THE DESIGN AND EVALUATION OF AN AMBIENT BIOFEEDBACK DISPLAY

A Thesis Submitted to the College of

Graduate Studies and Research

In Partial Fulfillment of the Requirements

For the Degree of Master of Science

In the Department of Computer Science

University of Saskatchewan

Saskatoon, CANADA

By

Brett Taylor

PERMISSION TO USE

In presenting this thesis in partial fulfilment of the requirements for a Postgraduate degree from the University of Saskatchewan, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of the Department or the Dean of the College in which my thesis work was done. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of Saskatchewan in any scholarly use which may be made of any material in my thesis.

Requests for permission to copy or to make other use of material in this thesis in whole or part should be addressed to:

Head of the Department of Computer Science
176 Thorvaldson Building
110 Science Place
University of Saskatchewan
Saskatoon, Saskatchewan
Canada
S7N 5C9

ABSTRACT

People use non-verbal cues, such as facial expressions, body language and tonal variations in speech, to help communicate emotion; however, these cues are not always available in interactive computer environments. For example, in computer-mediated communication, these cues don't exist, and in interactive art, it is difficult to convey and represent emotion. Without being able to effectively communicate emotion, we can have difficulty relating to other people, and can lack self-regulation of our own emotional states. In this thesis, we propose to use abstract visual representations of emotion when regular emotion cues either don't exist or are not appropriate to the medium. Through pilot testing and two user studies, we create abstract visual representations of emotional state and show that the visualizations are naturally interpretable and suitable for at-a-glance understanding. Finally, to demonstrate their utility, we incorporate the visual representations of emotion into a biofeedback task using ambient displays. We show that participants are able to use the visualizations to self-regulate their physiological arousal.

ACKNOWLEDGMENTS

I would like to thank my supervisor, Regan Mandryk, for always being supportive throughout my research. I would also like to thank everyone in the Interaction Lab for creating an amazing and creative research environment. Finally, I'd like to thank my friends and family for always being supportive and encouraging.

CONTENTS

PERMISSION TO USE I

ABSTRACT II

ACKNOWLEDGMENTS III

CONTENTS IV

LIST OF TABLES VIII

LIST OF FIGURES IX

LIST OF ABBREVIATIONS/ACRONYMS XII

INTRODUCTION **1**
1.1 Problem 3
1.2 Motivation 3
1.3 Solution 3
1.4 Steps to Solution 4
1.5 Contributions 5
1.6 Thesis Outline 5

RELATED WORK **7**
2.1 Affect and Emotion 7
2.2 Measuring Affect 8
2.3 Emotional Response to Visual Stimuli 8
2.3.1 Colour and Geometry in Visual Art and Design 9
2.3.2 Movement 9
2.4 Generating Graphics with Emotional Content 10

VISUALLY REPRESENTING EMOTION: A PILOT **12**
3.1 Introduction 12
3.2 Creating Abstract Visual Representations of Emotion 12
3.2.1 Visual Characteristics 14
3.2.1.1 Colour 14
3.2.1.2 Geometry 15
3.2.2 Visualization Strategies 15

3.2.2.1 Compositional Strategy 1 & 2 15
3.2.2.2 Algorithmic Strategy 17
3.3 Evaluation 18
3.3.1 Study 1: Arousal and Valence Survey 19
3.3.2 Study 2: Categorical Survey 21
3.4 Results 21
3.4.1 Survey Results 21
3.4.2 Analysis of Visual Characteristics 23
3.4.2.1 Compositional Strategy 23
3.4.2.2 Algorithmic Strategy 24
3.5 Discussion 25
3.5.1 Designing Abstract Visual Representations of Emotion 25
3.5.2 Limitations and Future Work 27
3.6 Conclusion 27

VISUALLY REPRESENTING EMOTION 29
4.1 Introduction 29
4.2 Generating Visual Representations of Emotion 29
4.3 Evaluation 32
4.3.1 Study 3 33
4.3.2 Study 4 35
4.4 Results 36
4.4.1 Identifying the Intended Emotion Quadrant 36
4.4.2 Differentiating Visualizations 37
4.4.2.1 Valence 39
4.4.2.2 Neutral 40
4.4.3 Identifying Transitions in Visualizations 40
4.4.4 Summary of the results 42
4.5 Discussion 43
4.5.1 Interpreting Abstract Visualizations of Emotion 43
4.5.2 Using Animation in Visual Representations of Emotion 45
4.6 Conclusion 45

EVALUATION OF AN AMBIENT BIOFEEDBACK DISPLAY 47
5.1 Introduction 47
5.2 Related Work 48
5.2.1 Arousal and Task Performance 48
5.2.2 Effect of Arousal on Memory 50
5.2.3 Ambient Displays and Ambient Influence 50
5.3 Designing Ambient Displays 52
5.3.1 Peripheral Display 53
5.3.2 Immersive Display 54
5.4 Experiment 54
5.4.1 Tasks 55

5.4.1.1 Jigsaw Task 55
5.4.1.2 Iconic Memory Task 56
5.4.2 Biofeedback Visualizations 57
5.4.3 Conditions 58
5.4.4 Measures 59
5.4.5 Procedures 60
5.4.6 Data Analyses 61
5.5 Results 61
5.5.1 Self-Report of Arousal 62
5.5.1.1 Habituation Effect 62
5.5.1.2 By Trial 63
5.5.1.3 By Arousal Level 64
5.5.1.4 Summary 65
5.5.2 Iconic Memory Test 66
5.5.2.1 Learning Effect 66
5.5.2.2 By Trial 67
5.5.2.3 By Arousal Level 67
5.5.2.4 Summary 69
5.5.3 Post-Condition Questionnaires 69
5.5.3.1 Quantitative 70
5.5.3.2 Qualitative/Long Answers 72
5.5.4 Post-Study Questionnaires 73
5.6 Discussion 76
5.6.1 Arousal Manipulation 76
5.6.2 Measuring Memory Performance 76
5.6.3 Learning Effects 77
5.6.4 Ambient Influence 78
5.6.5 Awareness Displays and Preference 79
5.6.6 Yerkes-Dodson Law 79
5.7 Conclusion 80

General discussion 82
6.1 Visually Representing Emotion 82
6.1.1 Strategies for Creating Visual Representations of Emotion 82
6.1.2 Interpreting Visual Representations of Emotion 83
6.1.3 Implications for Design 84
6.2 Designing for Ambient Influence 85
6.3 Applications 86
6.4 Limitations and Future Work 87
6.4.1 Limitations 88
6.4.2 Future Work 88

Conclusion 90
7.1 Summary of Findings 91

7.2 Contributions 92
7.3 Conclusion 93

REFERENCES 94

APPENDIX A: STUDY CONSENT FORMS AND QUESTIONNAIRES 99

APPENDIX B: PILOT STUDIES DATA TABLES 106

APPENDIX C: IAPS AND IADS STIMULI SELECTED 109

APPENDIX D: VISUAL REPRESENTATIONS OF EMOTION GENERATED BY EMOTIVIZ110

LIST OF TABLES

Table 1 Compositional strategies used by quadrant. 16

Table 2 Parameters used in algorithmic strategy. 18

Table 3 Compositional strategy results 24

Table 4 Algorithmic strategy results 25

Table 5 Summary of Visual Characteristics 26

Table 6 Frequency of choice of emotion quadrant by stimulus. Italicized text indicates predicted. 36

Table 7 p-values for pairwise comparisons between stimuli for arousal. Light shaded cells indicate a comparison of major difference; dark shaded cells indicate a comparison of predicted minor difference; white cells indicate no predicted difference. 38

Table 8 p-values for pairwise comparisons between stimuli for valence. Light shaded cells indicate a comparison of major difference; dark shaded cells indicate a comparison of predicted minor difference; white cells indicate no predicted difference. 39

Table 9 Stimuli differences for neutral stimuli. * indicates significant with p≈.000, # indicates significant with p < .05 and empty cells indicate p=1.00. 40

Table 10 Frequency of responses by stimuli. 41

Table 11 Chi-squared test results for Study 4. Bold predicted category text indicates the predicted category matched the most frequently selected category. 42

Table 12 Effects of arousal manipulation for each display condition. 65

Table 13 Statistical analysis of post-study questionnaire results. 72

LIST OF FIGURES

Figure 1 Discrete semantic labels of emotion (left); Emoticons (right). 2

Figure 2 Colours selected for low through high valence. 14

Figure 3 Sample visualizations (clockwise from top left): compositional high arousal/negative valence; compositional high arousal/positive valence; algorithmic high arousal/positive valence; algorithmic low arousal/negative valence. 17

Figure 4 Locations of Russell's circumplex used in evaluation. 19

Figure 5 Self-assessment manikin for arousal and valence used in survey 1. 20

Figure 6 Results for high arousal, negative valence. Chart shows predicted value and actual results for each stimulus for Location 1 (high arousal, negative valence). Markers represent mean values across participants; error bars show standard deviation for arousal ratings (vertical) and valence ratings (horizontal). 22

Figure 7 Abstract visual representations of emotion generated by EmotiViz. 30

Figure 8 Locations of Study 3 stimuli in AV space. 33

Figure 9 Study 4 stimuli (Q1-Q12). 35

Figure 10 Arousal-valence plot of mean SAM ratings from Study 3. Error bars show standard deviation. 38

Figure 11 Study 4 stimuli. Each line represents the direction of transition in the stimulus clip (blue for arousal, red for valence). Dotted lines indicate no statistically significant difference; solid lines indicate significant differences; thick solid lines indicate significance matching the predicted category. 41

Figure 12 The Hebbian version of the Yerkes-Dodson Law. (Public domain; from Wikipedia, http://en.wikipedia.org/wiki/Yerkes%E2%80%93Dodson_law) 49

Figure 13 Peripheral display. 53

Figure 14 Immersive display. 54

Figure 15 Jigsaw Puzzle task. Initial image exposure (left) and scrambled jigsaw image (right). 56

Figure 16 Iconic memory test. Step 1, letters appear (above); step 2, letters disappear and text entry appears (below). 57

Figure 17 Experimental room setup. 60

Figure 18 Habituation effect of the IAPS and IADS stimuli. Average self-reported arousal rating by arousal level. 62

Figure 19 Average self-reported arousal by trial based on first exposed condition. 63

Figure 20 Average arousal between participants by first exposure. 64

Figure 21 number of letters recalled by arousal level for each experimental exposure. ...66

Figure 22 Average number of letters recalled correctly by trial for each condition, by first exposed condition. 67

Figure 23 Sum of letters recalled correctly by arousal level for each display condition, based on condition to which participants were first exposed. N=4 per condition. 68

Figure 24 Average of responses to affected by the visualizations (1=disagree, 7=agree). Error bards show standard deviation. 70

Figure 25 Average of responses to memory and puzzle task difficulty (1=easy, 7=difficult). Error bards show standard deviation. 70

Figure 26 Average of responses to regulating physiology using display (1=disagree, 7=agree). Error bards show standard deviation. 70

Figure 27 Average of responses to frequency looked at display (1=disagree, 7=agree). Error bards show standard deviation...71

Figure 28: Distribution of responses to memory task performance questions. 74

Figure 29: Distribution of responses to puzzle task performance questions. 74

Figure 30: Distribution of responses to awareness question. 74

Figure 31: Distribution of responses to condition preference. 75

LIST OF ABBREVIATIONS/ACRONYMS

HCI	Human Computer Interaction
IM	Instant messaging
YDL	Yerkes-Dodson Law

CHAPTER 1

INTRODUCTION

Expressing our emotion is critical for our interpersonal relationships to succeed (Ashkanasy et al., 2000). We constantly communicate how we feel when we interact with other people. In face-to-face communication, people use emotion cues, such as tonal variations in speech, body language, and facial expressions, to communicate how they feel (Bernieri, 1988).

Modern technology has created situations where these cues do not exist or are not appropriate for the environment. For example, these cues don't currently exist in computer-mediated communication (e.g., text messaging, instant messaging, email), or when an individual is working at their computer and needs to control their emotions (e.g., avoid stress, stay positive). Furthermore, representing emotion is common in interactive art projects, such as in Mood Swings (Bialoskorski et al., 2009), where illuminated spheres were used in an art installation to represent emotion.

Current attempts to convey emotion cues in computing environments do not work well and are not always appropriate for the type of application. Conveying emotion using expressive language, such as discrete labels of emotion, is limited to a common language and vocabulary. It also tends to be difficult for people to do well, and does not always suit the medium or environment. For example, using discrete semantic labels of emotion (see Figure 1, left) would be difficult or inappropriate in an interactive art project that represents or conveys emotion. Emoticons (see Figure 1, right) have been used in computer-mediated communication, but these are also limited to a discrete set of emotions and sometimes require instruction to interpret. Similar to the problems described for expressive language, emoticons would also pose difficulty when representing emotion in interactive art projects, since there is likely a media mismatch and it would be difficult to capture the natural ebb and flow of emotion in these types of work.

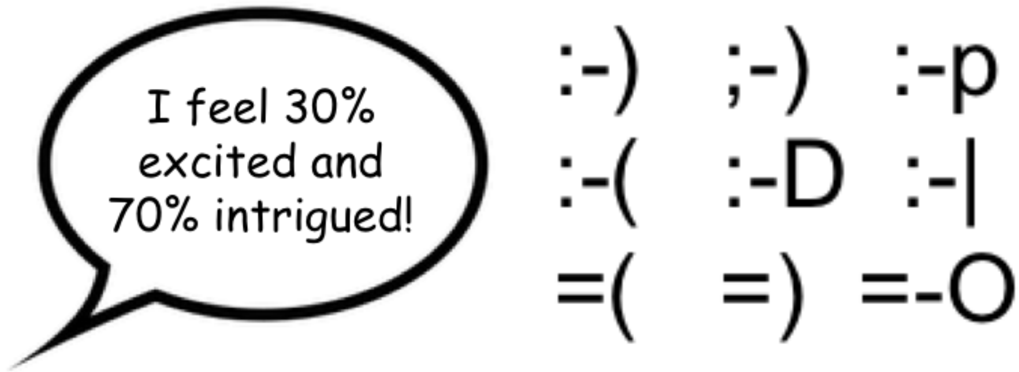


Figure 1 Discrete semantic labels of emotion (left); Emoticons (right).

Recent attempts to convey emotion in interactive systems have used abstract visual representations of emotion. For example, eMoto (Sundström et al, 2005) helps people convey emotion in mobile environments using visualizations, but because there is no absolute mapping between the visualization and an encoded emotion, interpretation is highly relevant to the pair and their consistent use of the software. A second example is the Subtle Stone (Balaam et al., 2010), which is used in classrooms to communicate students' emotion to their teacher. Subtle Stone requires each student and teacher pair to agree on a colour-emotion mapping, which varied for each student, requiring teachers to remember the mappings for each student or carry with them a cipher. This makes Subtle Stone only useful for at-a-glance understanding if the teacher can memorize, and quickly and consistently remember, all the mappings.

No existing work has generated abstract visual representations of emotion that are useful for at-a-glance understanding, without requiring instruction or training prior to use and that suit a variety of media. This thesis explores a system for creating abstract visual representations of emotion that are useful for at-a-glance understanding.

1.1 PROBLEM

There is currently no way to represent emotion in computing environments that is usable for at-a-glance understanding and that suits a variety of media.

1.2 MOTIVATION

Expressing our emotion is critical for interpersonal relationships to succeed (Ashkanasy et al., 2000). We are less engaged and less interested in communicating with other people when we cannot effectively express how we feel (Russell et al., 1989; Yelsma and Marrow, 2003). This negatively affects our interpersonal relationships and it is more difficult for us to work well with other people, decreasing group productivity (Ashkanasy et al., 2000).

We naturally express emotion cues (e.g., facial expressions, tone of voice) that are easily recognized. These cues are organic and people understand them immediately with a short glance. If there are long delays by people in interpreting cues such as facial expressions, it would interrupt the natural flow of communication. With that in mind, any attempt to represent or convey emotion in computing environments should meet these same requirements. Whether communication is face-to-face or over a digital medium, interpreting a digital representation of emotion should be understandable with a short glance.

1.3 SOLUTION

Our solution is to create abstract visual representations of emotion that can be used in computing environments that are useful for at-a-glance understanding. We also explore their efficacy when displayed on peripheral and immersive ambient displays using a biofeedback training task.

Visual representations of emotion are useful in a variety of environments. As previously described, they could be used in digital communication environments where regular emotion cues either don't exist or can't be used. Our visualizations could be used on public ambient displays to visualize the emotional experience of a group viewing a performance or art installation. They could also be used as an integral component of an art installation. In the home, they could be used to visualize the mood of a family. Or alternatively, they could be used to help close relatives separated by a distance stay emotionally connected by providing a real-time visualization of the mood of a remote relative. Finally, they could be used to augment traditional emotion cues in face-to-face communications for people who have difficulties interpreting these cues, such as people with Autism Spectrum Disorder.

1.4 STEPS TO SOLUTION

There are three steps to our solution.

First, we design abstract visual representations of emotion that are useful for at-a-glance understanding without prior training. We do this by drawing from other fields where conveying emotion is important, such as visual art and movement in dance. We design abstract visual representations using three approaches. (1) *Compositional*, drawing from art theory to create static images; (2) *Algorithmic*, taking a more structured approach to create static images with more visual consistency; and (3) *Hybrid Compositional and Procedural*, using compositional by quadrant to create procedurally-animated visual representations that transition between states smoothly.

Second, we conduct a series of user studies to determine whether the abstract visual representations of emotion are interpretable and to determine what types of visual representations work best for natural at-a-glance understanding. We show that our visual representations are identifiable by Russell's (1980) emotion quadrant and that people can identify transitions in the visualized emotion state.

Third, we compare the efficacy of our representations as displayed peripherally or immersively for providing feedback of emotion cues to a user during a biofeedback training task. We show evidence that participants may be able to use the visual representations of emotion to self-regulate their physiological arousal.

1.5 CONTRIBUTIONS

This thesis provides three main contributions.

1. We are the first to create abstract visual representations of emotion that can be used in a digital environment to convey or communicate emotion without prior training useful for at-a-glance understanding.

2. We demonstrate that visual representations of emotion can be used on ambient displays for biofeedback tasks.

3. Finally, we demonstrate evidence that suggests people can use visual representations of emotion for biofeedback task to self-regulate their physiological arousal.

1.6 THESIS OUTLINE

In Chapter 2, we outline related research, which we use to build our visual representations of emotion. We begin with an overview of an overview of emotion and affect, and move on to describe other work that has attempted to visually convey or represent emotion.

Chapter 3 describes our first attempt at creating visual representations of emotion. In these pilot tests, we create a system for generating these visual representations and evaluate them.

Chapter 4 builds on Chapter 3, by developing a hybrid strategy for creating visual representations of emotion. We also present empirical results of our user study.

Chapter 5 uses the visual representations of emotion created in Chapter 4 in a biofeedback application using ambient displays.

Chapter 6 discusses the results from our user studies, outlines design recommendations and discusses future work.

Finally, Chapter 7 summarizes the work in this thesis and our contributions.

CHAPTER 2

RELATED WORK

In this thesis, we are concerned with visually representing emotion. In order to do this, we need to understand emotion and existing techniques used to represent it. This chapter provides an overview of this related work in four areas. First, we provide background on affect and the models used to describe it. We then discuss techniques used to measure affect. Next, we explore work investigating the emotional response to visual stimuli. Finally, we look at ways in which existing work has used all of this information to generate visual stimuli with emotional content.

2.1 AFFECT AND EMOTION

The terms affect, emotion and mood are often used interchangeably. For the purposes of this thesis, we will use affect to describe the low-level response to a stimulus (e.g., increased heart rate), emotion to describe the cognitive interpretation of the response (e.g., excitement, fear), and mood to describe the state as emotions are experienced over time.

Near the turn of the 20th century, William James (Cacioppo and Tassinary, 1990) pioneered the physical theory of emotion. He suggested that discrete emotional experiences are identifiable by a unique marking of bodily changes and that the perception of these physiological changes is the cause of an emotional experiences (Picard, 1997). Following James and taking a different perspective, Cannon demonstrated that autonomic events do not contribute to an emotional experience (Cacioppo and Tassinary, 1990). He instead believed that emotions are cognitive, originating from the brain and without any sensation in the body (Picard, 1997). Modern research has shown that emotion originates from both the physical and cognitive theories developed by James and Cannon.

There are two approaches used in modern psychology to describe emotions: categorical and dimensional. Ekman (2005) proposed a categorical model where semantic labels (e.g., pride, fear) are applied to discrete states. Russell (1980) proposed a dimensional model (circumplex model) where emotions are represented by two orthogonal axes called arousal and valence. Arousal describes the energy or activation of an emotion and is a continuum between high activation (positive arousal) and low activation or sleepiness (negative arousal). Valence describes the pleasure (positive valence) and displeasure (negative valence) of an emotion. The circumplex model can be used to describe categorical emotion labels (Russell, 1980). For example, anger would be high arousal, negative valence, whereas as a feeling of relaxed would be low arousal, positive valence.

2.2 MEASURING AFFECT

The arousal and valence dimensions have been used for emotion assessment. Although there are many methods for measuring emotion, we focus on methods for measuring emotion using visual representations of arousal and valence. Based on their circumplex model, Russell et al. (1989) developed the affect grid as a tool for participants to quickly assess affect in terms of arousal and valence. To avoid using semantic labels, Bradley and Lang (1994) developed the self-assessment manikin (SAM) as a 9-point pictorial scale for subjective self-report of arousal and valence. The SAM provides a fast and language-agnostic way of assessing emotional state (see figure 1 in Bradley and Lang (1994)). One drawback to the arousal-valence approach of representing emotion is that the two orthogonal dimensions might not be completely independent (Lang et al., 1993). For example, if a feeling is truly unpleasant, it is unlikely to also have very low arousal.

2.3 EMOTIONAL RESPONSE TO VISUAL STIMULI

Many researchers have focused on user response to real photographs. Lang et al. (2008) created the International Affective Picture System (IAPS)—a set of photographs for use as experimental stimuli. They used the SAM to measure the emotional response to the images, and this image set has become a standard visual stimuli for measuring emotional response.

We are instead interested in abstract representations of emotion, and base our approach on literature on the emotional response to visual stimuli.

2.3.1 Colour and Geometry in Visual Art and Design

Researchers have evaluated the emotional content of visual stimuli from the perspective of visual art and design. Valdez and Mehrabian (1994) evaluated colours using arousal and valence. They found blue to be the most pleasant colour and yellow to be the least pleasant. They also found that more saturated and less bright colours are more arousing. Simmons (2006) supported their findings; however, Hevner (1935) found that red is happy and exciting but blue is serene, sad and dignified. Clarke and Costall (2008) performed interviews to determine that warm colours were associated with feelings of anger and rage while green and blue were associated with low anxiety. Kaya and Epps (2004) coded open-ended responses into positive and negative emotions to find that green is the most positive colour and yellow-green is the most negative. From colour theory in visual art, Itten (1970) describes the compositional effects of colour contrast. While he does not use terms used in Russell's model of emotion, we can infer that the use of high contrast colours is more activating.

Mono (1997) wrote that circles, spirals, and shapes with smooth curves were more pleasant than shapes with hard angles. Hevner (1935) found a relationship between line style and emotion. Curves were found to be serene while hard angles were found to be agitating. Halper et al. (2003) found a relationship between line style and perceptions of safety—objects rendered using jagged lines were perceived as more dangerous than objects rendered using smooth lines.

2.3.2 Movement

Detenber et al. (1998) used the SAM and physiological measures to assess the effects of motion on arousal. They found a positive relationship between increased motion and arousal. Arnheim (1956) observed that animations featuring mechanical movements demonstrated less emotion than more natural movements. Boone and Cunningham (1998) asked children to label dance moves as angry, fearful, happy or sad and found that children were able to correctly decode the intended emotion of the dancers. They extracted body movements to determine that angry movements involved directional and tempo changes, fearful movements involved rigidity in the body, happy movements included many upward movements of the arms, and sad movements included extended periods of downward gaze.

2.4 GENERATING GRAPHICS WITH EMOTIONAL CONTENT

Work in the previous section focused on evaluating emotional content; we now describe work that has focused on generating graphics with emotional content.

Ibanez (2011) created a system to represent emotion using abstract imagery by varying movement and symmetry. The results from his user study suggest that movement and symmetry worked for expressing arousal and valence, respectively. Ibanez did not find that participants could identify small degrees of granularity in arousal or valence, only that they were able to identify discrete emotions representing the quadrant of Russell's circumplex to which they belonged.

Sundström et al. (2005) created eMoto to express emotion in mobile messaging using colour, shape and animation. They did not find that the visualizations were interpreted consistently between users. They observed that participants tended to vary the representation of emotion based on the recipient of the message. This implies that their solution is not a generalizable means of creating visualizations of emotion.

Shugrina et al. (2006) and Colton et al. (2008) created systems to generate images using non-photorealistic rendering (NPR) techniques based on viewer emotion as detected by facial expression recognition. However, both of these systems focused on choosing appropriate NPR styles and rendering appropriate imagery. Neither system was evaluated to determine whether the choice of NPR algorithm conveyed the intended emotion. However, Mould et al. (2012) evaluated the effects of NPR techniques using IAPS images and found that some algorithms dampened affective response to stimuli because of the meaningless and distracting artifacts produced by the algorithms.

Balaam et al. (2010) created physical objects (Subtle Stones) used by students in classroom environments to communicate their emotion to the teacher. Emotion was represented by the colour the Subtle Stone displayed and students and teachers had to agree in advance on a mapping between colour to discrete emotional state.

While all of these existing efforts have been successful in some respects, none has been systematically shown to be interpretable without prior training. Nor have they been used for at-a-glance understanding. As a result, further investigation is necessary to determine how to do this. In the next chapter, we will discuss our first approach to create visual representations of emotion.

CHAPTER 3

VISUALLY REPRESENTING EMOTION: A PILOT

3.1 INTRODUCTION

In the last chapter, we learned how existing techniques have been used to create visual representations of emotion with emotional content. However, none of these were successful at being interpreted without prior training for at-a-glance understanding. In this chapter, we discuss our first attempt to create abstract visualizations to represent emotion. Our approach used two strategies to create static imagery for representing emotion using arousal and valence. We evaluate the visual representations we created in a two-part user study. As the results were somewhat inconclusive in terms of the efficacy of our visualizations, we treat these studies as pilot experiments for the designs shown in Chapters 4 and 5. As such, details on the results of statistical tests have been moved to Appendix B.

3.2 CREATING ABSTRACT VISUAL REPRESENTATIONS OF EMOTION

In Chapter 2, we described techniques used in existing work to create visual representations of emotion. We concluded that none of the existing strategies was suitable for at-a-glance understanding without prior instruction. In this section, we describe how we created EmotiViz to meet our design goals.

We chose to create abstract representations rather than concrete representations for several reasons. First, concrete representations are limited in their power to express emotion. Semantic labels are limited to what language can express, the use of language is limited to situations where users have a common language, and emoticons are limited to discrete emotions that don't facilitate gradations.

Second, we cannot easily aggregate the emotion of multiple people with concrete representations. While tag clouds of semantic labels are a possibility, they are not quickly interpreted and often require thoughtful analysis to understand. In addition, concrete representations like semantic labels or emoticons cannot be averaged to create a succinct aggregate model for a group.

While it has been suggested that emotion cannot be expressed or experienced without context, abstract visualizations based on discrete emotion labels from Russell's circumplex (e.g., anger) are easily understood and expressed without context in our experiment. We replace a semantic label (e.g., "excited") or position in arousal-valence space (e.g., high arousal-positive valence) with an abstract visualization, which our participants interpret consistently. We believe abstract representations to be more suitable for many types of applications and environments. Because colour, geometry, and motion are faster to process and less distracting than textual information (Ware, 2004), our visualizations are more suitable for use in applications where providing ambient or peripheral information is critical. Furthermore, the abstract visual nature is more likely to transcend culture than a more concrete representation.

We created EmotiViz to generate representative visualizations of emotion based on arousal and valence values (1-9, 1=low, 9=high). EmotiViz was written in Java and produces PNG images 400x400 pixels in dimension. Image generation was divided into 2 strategies: compositional and algorithmic. The compositional strategy uses different approaches for each quadrant of Russell's circumplex. The algorithmic strategy uses a more procedural and mathematical approach to generate visualizations. We used different strategies so we could test different variations for their effectiveness in representing emotion.

We first discuss the visual characteristics used in our implementation and we then discuss how they were used in each of the visualization generation strategies.

3.2.1 Visual Characteristics

Because many of the sources we found considered visual characteristics independently, we concluded that a combination of characteristics expressing the same emotion could produce abstract representations of emotion that are interpretable at-a-glance without prior instruction.

3.2.1.1 Colour

We decided to use the findings of Valdez and Mehrabian (1994) to select a background colour. For valence, we used the relationship they found for colour hue (wavelength). Unfortunately, the negative to positive valence continuum found experimentally was not a smooth flow of hue, from low to high wavelengths. As a result, we decided to map from the most pleasant to least pleasant colours ignoring incongruous jumps in the colour spectrum. We converted the pleasure (valence) scale used by Valdez and Mehrabian into a relative scale such that colours were considered for their relative level of valence rather than the absolute scale used. We did this in order to have an equal number of colours on each side of the valence scale. We ignored the divergence of arousal and valence with colour hue (e.g. green-yellow was found to be most arousing) to focus on the relationship of hue to valence. The colours chosen from least pleasant to most pleasant are shown in Figure 2.

Figure 2 Colours selected for low through high valence.

For arousal, we also used the findings by Valdez and Mehrabian (1994): more saturated and less bright colours were found to be more arousing. For each value of valence (mapped to a single hue), we varied the saturation and brightness by arousal. Colours selected for high arousal were highly saturated and less bright while colours for negative arousal were much less saturated and much less bright.

For foreground colour, we borrowed from Itten (1970) and Albers (2006), and associated colour contrast with arousal: higher contrast foreground colours are more arousing. We also associated the number of foreground colours used with arousal: a higher quantity of colours is more arousing.

3.2.1.2 Geometry

For geometry, we based our approach on those used by Shugrina et al. (2006) and Sudstrom et al. (2005). From Hevner (1935) and Mono (1997), we associated curving lines and shapes with positive valence while we associated lines and shapes with hard angles with negative valence. We also associated higher quantity of foreground objects with high arousal, based on artistic composition described by Itten (1970). Additionally, we associated shapes and lines that appear to move off the canvas with high arousal. Finally, we associated high symmetry with positive valence based on the findings of Ibanez (2011).

3.2.2 Visualization Strategies

We used two strategies for creating abstract representations of emotion: a compositional strategy and an algorithmic strategy.

3.2.2.1 Compositional Strategy 1 & 2

In this strategy, we varied the approach for each quadrant of Russell's circumplex. We developed two different techniques for each of the quadrants in order to test different variations. We called these compositional approach #1 and #2. Table 1 describes the elements and the source of inspiration. Figure 3 shows example visualizations. See Appendix D for more examples of the visualizations.

Table 1 Compositional strategies used by quadrant.

Region	**Compositional #1**	**Compositional #2**
Quadrant 1 (low V, high A)	Jagged shapes (spikes) of high contrast colour (Hevner, 1935; Itten, 1970; Mono, 1997)	Random placement of randomly sized circles of high contrast colours (Itten, 1970)
Quadrant 2 (high V, high A)	Arranged pattern of circles of complementary colours (Hevner, 1935; Ibanez, 2011; Itten, 1970)	Arranged pattern of circles of complementary colours of varying number per row (Hevner, 1935; Ibanez, 2011; Itten, 1970)
Quadrant 3 (low V, low A)	Parallel, horizontal lines at bottom edge of canvas (Itten, 1970)	Non-parallel, horizontal lines in lower third of canvas (Albers, 2006; Itten, 1970)
Quadrant 4 (high V, low A)	Three inline circles of low contrast colours (Hevner, 1935)	Three diagonal circles of medium contrast colours (Hevner, 1935)
Neutral Arousal	Single square, at centre of a low contrast colour (Hevner, 1935)	Single square, at centre of a high contrast colour (Hevner, 1935)
Neutral Valence	5 squares, one at each corner plus the centre, varying in size by arousal; high contrast colour (Hevner, 1935; Itten, 1970)	5 squares, one at each corner plus the centre, varying in size by arousal; medium contrast colour (Hevner, 1935; Itten, 1970)

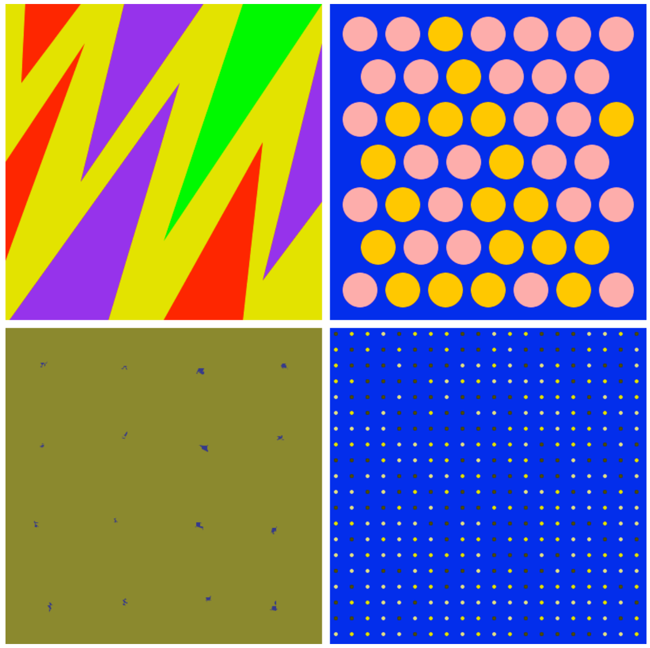


Figure 3 Sample visualizations (clockwise from top left): compositional high arousal/negative valence; compositional high arousal/positive valence; algorithmic high arousal/positive valence; algorithmic low arousal/negative valence.

3.2.2.2 Algorithmic Strategy

The algorithmic strategy takes our understanding of composition, but applies it in a more methodical approach with less variation between quadrants. We varied parameters of the visual representations based on arousal and valence values. In doing so, a single step in arousal or valence value is more visually consistent than in the compositional strategy. Table 2 describes the parameters used in the generation of visual representations and the source. Figure 3 shows example visualizations.

Table 2 Parameters used in algorithmic strategy.

Parameter	Dimension	Description
Quantity of objects	Arousal	Higher quantity → higher arousal (Itten, 1970)
Geometry (number of polygon points)	Valence	Fewer polygon points → higher valence (negative valence = many-sided polygons, positive valence = circles) (Hevner, 1935, Shugrina et al., 2006)
Object symmetry (arrangement)	Valence	More symmetrically arranged → higher valence (Ibanez, 2011)
Colour contrast	Arousal	More contrast → more arousing (Itten, 1970)
Number of foreground colours	Arousal	More colours used suggests more contrast → higher arousal

3.3 EVALUATION

To evaluate EmotiViz, 39 images were generated representing 13 discrete locations on Russell's circumplex. Two images were created using the compositional strategy and one image was created using the algorithmic strategy. The extreme values of each dimension plus neutral locations and mid-way points were chosen. Figure 4 shows the 13 locations selected.

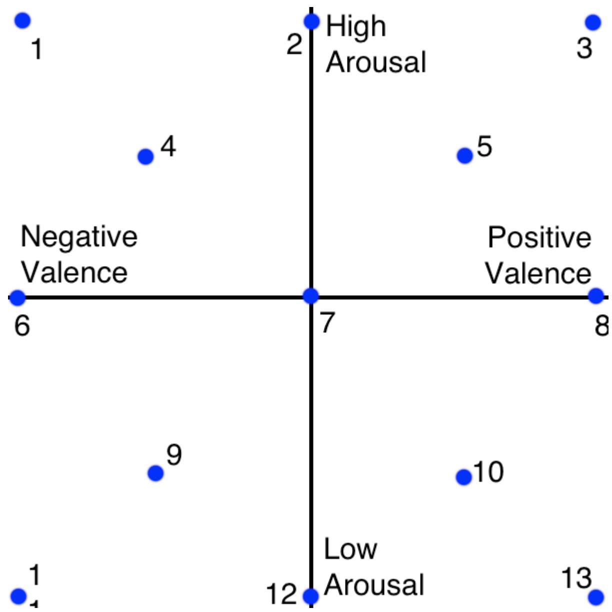


Figure 4 Locations of Russell's circumplex used in evaluation.

Two online surveys were conducted to evaluate the 39 images. We used Google Forms to host the surveys. Participants were recruited from the Interaction Lab at the University of Saskatchewan and from Facebook.

Because participants were able to complete the online surveys in their own environment, several potential confounds could not be controlled. These include, among others, the aural environment (background noise/music), the type of screen and colour calibration used, how quickly the participants proceeded through the questionnaire and whether they took a break or were multitasking. We considered these confounds a trade-off in order to get a higher number of subjects and a more ecologically valid study.

3.3.1 Study 1: Arousal and Valence Survey

In the first survey, participants were asked to rate each of the 39 images using the 9-point Self-Assessment Manikin (SAM) (Bradley and Lang, 1994) scale for arousal and valence. To control exposure to image generation techniques, a Latin Square was used to balance the order in which participants saw the visualization strategies. Otherwise, the images were displayed using a systematic ordering based on location on the affective grid (starting with location 1 in the top left corner and proceeding to location 13 in the bottom right corner). The Google Form was modified to include the SAM in place of a standard Likert scale. Figure 5 shows the arousal and valence SAM scales used.

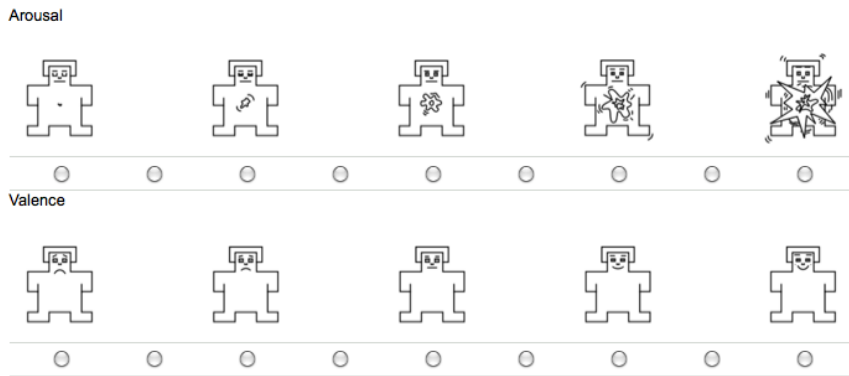


Figure 5 Self-assessment manikin for arousal and valence used in survey 1.

We piloted the first survey with 3 participants (2 female) to verify that the online survey mechanism was bug free. Pilot participants were also asked to complete a Positive and Negative Affect Schedule (PANAS) (Watson et al., 1988) for each stimulus following use of the SAM. The PANAS was used to determine whether pilot participants were responding as predicted when using the SAM.

We had 26 participants (12 female) respond to the online survey. Participants were asked for demographic information in order to determine their cultural background. Eight participants indicated that their first language was not English or otherwise qualified as being from a non-North American cultural background (no participant data was discarded due to cultural background). Participants were also tested for colour vision deficiency (CVD) using the Ishihara Colour Test (1959). Four public domain images were used as a test for CVD. One participant's responses indicated achromaticity; as a result we discarded his/her data. We elected to keep another participant's data whose responses indicated dichromaticity.

3.3.2 Study 2: Categorical Survey

In the second survey, participants were asked to rate the same images (in the same order they saw them in the first survey) using categorical responses. Of the original 26 participants, 21 responded to the follow-up survey. For each image, participants were asked to select the set of words that best describe the emotion conveyed in the corresponding image. Four categories, each consisting of a pair of discrete emotions representing each of the four quadrants of Russell's circumplex were used. This technique is based on that used by Ibanez (2011). Note that locations with neutral valence or neutral arousal were not represented in the categorical responses. The categories used were:

- Angry, enraged (high arousal, negative valence)
- Excited, joyful (high arousal, positive valence)
- Bored, sad (low arousal, negative valence)
- Calm, satisfied (low arousal, positive valence)

3.4 RESULTS

In this sub-section, we discuss the results from the EmotiViz evaluation studies. Our online studies were designed to evaluate whether the visual representations of emotion created were useful for at-a-glance understanding without prior training. To evaluate this, we first needed to know whether the visual representations conveyed the intended emotional state to people.

3.4.1 Survey Results

Participants' ratings of the images using arousal and valence (SAM scale) showed little significant agreement with the predicted values. For example, Figure 6 shows the predicted arousal and valence values for location 1 and the mean values (across participants) of the three experiment stimuli for location 1. We ran one-sample t-tests using the sample arousal and valence values and found a significant difference ($p<0.05$) between the sample values and the predicted value in the majority of cases. This means that in the majority of cases the predicted mean did not closely match the sample mean. In the remaining cases, several stimuli did show strong agreement between the sample mean and the predicted values (see Appendix B for details). These tended to be stimuli that did not have extreme values of arousal or valence.

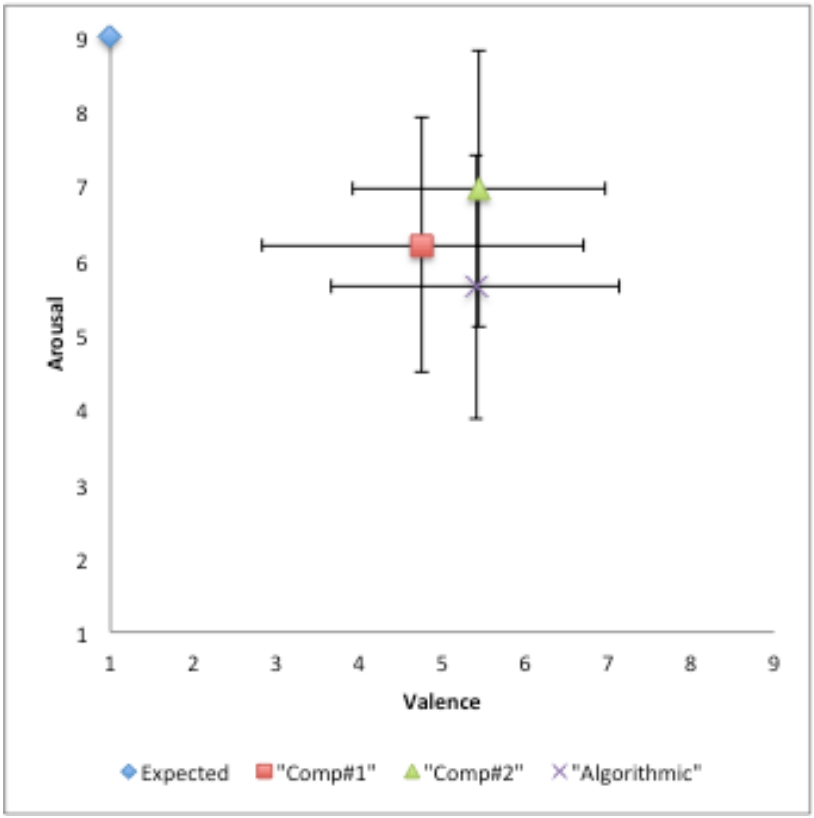


Figure 6 Results for high arousal, negative valence. Chart shows predicted value and actual results for each stimulus for Location 1 (high arousal, negative valence). Markers represent mean values across participants; error bars show standard deviation for arousal ratings (vertical) and valence ratings (horizontal).

To analyze the results of the categorical data, we conducted chi-squared tests for each stimulus to determine whether participants chose the predicted quadrant. We found that 17 of the 24 non-neutral stimuli (that is, those that have neither neutral arousal or valence) were significant ($p<0.05$ – see appendix B for data tables). Of those, 12 matched the predicted quadrants. It is worth noting that 2 of the 5 that did not match the predicted quadrants were stimuli containing a high number of circles randomly placed with high colour contrast. These were predicted to be angry/enraged but were rated as happy/sad.

We further found that 7 of the 15 neutral stimuli reached significance ($p<0.05$). Because the words chosen in the second survey did not, by design, leave room for granularity in neutral arousal or valence, the analysis was more subjective (because neutral locations do not technically belong to a quadrant). However, if we consider locations 2, 6, 8 and 12 (ignoring neutral arousal/neutral valence location 7), we can inspect the selected words to determine whether the quadrant selected falls on the correct side of one of the axes. For example, we can consider whether the words selected for location 2 match quadrant 1 or 2, both of which indicate high arousal. By doing so, we can say that 5 of the 7 significant ratings for the neutral categorical data were rated correctly.

3.4.2 Analysis of Visual Characteristics

Because only half of our stimuli matched the predicted emotional quadrant, we wanted to explore participant response to the underlying visual characteristics used to convey emotion (described in Table 1 and Table 2). We first present results for the compositional strategy and then the algorithmic strategy.

3.4.2.1 Compositional Strategy

For the compositional strategy, we compared stimuli with common characteristics of shape, quantity of foreground objects, object pattern and background colour. To do this, we took the overall mean of two stimuli with different expressions of the same characteristic. For example, we compared two stimuli with hard spikes against two stimuli with horizontal lines for the shape group. Each group was compared for either arousal or valence but not both. This is because the stimuli selected for each expression were chosen to convey change along a single dimension (either arousal or valence). We used a Wilcoxon test to determine if there was a significant difference between the expressions of the characteristic groups. The following table shows how images were grouped and the results.

Table 3 Compositional strategy results

Characteristic	**Expression**	**Overall Mean (SD)**	**Wilcoxon Test**
Shape (*Arousal*)	Spikes	6.28 (1.82)	Z=-4.262, p=.000
	Lines	3.18 (1.31)	
Qty of Objects (*Arousal*)	High qty	4.54 (1.84)	Z=-3.424, p=.001
	Low qty	3.34 (1.43)	
Object Pattern (*Valence*)	Random	4.8 (1.46)	Z=-.630, p=.529
	Arranged	4.7 (1.21)	
Background colour (*Valence*)	Yellow	4.26 (1.35)	Z=13.762, p=.000
	Blue	5.76 (1.39)	

To summarize, we found there was a significant difference in arousal between stimuli with spikes and those with lines and also between the quantity of objects in the foreground. We further found a significant difference in valence between yellow and blue as a background colour with stable foreground shape. We did not find a significant difference between randomly arranged and symmetrically arranged foreground objects.

3.4.2.2 Algorithmic Strategy

To evaluate the algorithmic strategy, we took a similar approach to that used for the compositional strategy but evaluated three expressions for each characteristic. Each characteristic contained three different stimuli due to the parameterized nature of this strategy. We evaluated two visual characteristics: quantity of foreground objects and object pattern. For each characteristic, we first conducted a Friedman test to determine if there was a difference overall. If a difference was found, we conducted a Wilcoxon Signed Ranks test for pairwise comparisons. The following table shows the data. We found a significant difference between each of the expressions used for quantity of shapes to convey arousal. We did not find any significant differences in object pattern for valence.

Table 4 Algorithmic strategy results

Characteristic	Expression	Overall Mean (SD)	Tests
Qty of Objects (*Arousal*)	High qty	5.60 (1.70)	$X^2(2)$=33.835, p=.000 high-med: Z=-3.876, p=.000 med-low: Z=-3.824, p=.000 high-low: Z=-4.273, p=.000
	Med qty	4.48 (1.43)	
	Low qty	3.39 (5.05)	
Object Pattern (*Valence*)	Random	4.48 (0.90)	$X^2(2)$=2.523, p=.283
	Med	4.91 (1.13)	
	Arranged	5.05 (1.10)	

3.5 DISCUSSION

The majority of stimuli created was intended to convey extreme values of arousal and valence or both. The results show that in the majority of cases, participants did not find the stimuli as extreme as we had predicted. This is partly due to the phenomena of a tendency to favour values in the centre of Likert scales rather than extremes (Kamenica, 2008). Furthermore, the results suggest that our stimuli were not as extremely arousing or valent as we had predicted.

The results of our experiment when using categorical values to place stimuli in quadrants of Russell's circumplex proved relatively successful and demonstrated that a majority of participants placed half of the stimuli in the predicted quadrant. The most compelling evidence is for specific visual characteristics used, including quantity of objects and shape of objects to convey arousal, and background colour to convey valence.

3.5.1 Designing Abstract Visual Representations of Emotion

Based on the results of this study, we now discuss what we learned from our initial attempt to design abstract visual representations of emotion. We then use this information to aid in the design of our new visualizations in Chapter 4.

Table 5 Summary of Visual Characteristics

Element	**Observed Understanding**	**Categorical Evidence**	**SAM (Arousal/Valence) Evidence**
Primary background colour	Blue more positively valent than yellow	n/a	Comparison of compositional stimuli, background colour (Table 3)
Quantity of foreground objects	Higher quantity positively correlated with positive arousal	n/a	Comparison of algorithmic stimuli, quantity of objects (Table 4); comparison of compositional stimuli, quantity of objects (Table 3)
Geometry: circles	Positive valence	Significant agreement among participants of stimuli with circles in quadrants of positive valence	No significant findings from either compositional or algorithmic
Geometry: squares	Neutral valence	n/a	Sample means showed highest accuracy to predicted means among stimuli with squares that were neutrally valent (see appendix)
Geometry: bounded horizontal lines	Negative arousal, negative valence	Significant agreement among participants of compositional stimuli in quadrant 3	No significant findings
Geometry: hard angles	Negative valence	Significant agreement among participants of stimuli with spikes as negatively valent	No significant findings
	Positive arousal	n/a	Comparison of compositional stimuli, shape (Table 3)
Symmetry	None	n/a	Pattern and arrangement comparisons from both algorithmic and compositional showed no significance.

Table 5 summarizes our findings based on the visual characteristic used and the evidence we found. Briefly, background colour could not be independently verified due to the nature of our experiment, however, there was some evidence that blue is more positively valent than yellow. The quantity of foreground objects showed a strong relationship with arousal. Shapes with soft edges showed evidence of being more positively valent than ones with hard edges. Finally, we did not find any significant results in the arrangement of objects based on symmetry.

3.5.2 Limitations and Future Work

EmotiViz produced visualizations of emotion using a combination of visual characteristics such as colour and geometry. Because we relied on existing work on colour as a means to represent arousal and valence, we did not strictly focus on determining the relative affect of individual colours. As a result, one cannot take the colours we chose in our experimental stimuli and use them without the same combination of other visual characteristics and expect to represent the same affect. Our findings do not offer specific guidelines with respect to colour because of cultural and individual differences in colour interpretation and association.

Furthermore, although we did not find significant findings in support of symmetry, we do not believe this discredits the work by Ibanez (2011). There is likely a positive correlation between valence and symmetry when symmetry is used appropriately; in our stimuli, the symmetry used was more subtle and used in conjunction with other visual characteristics that were potentially more dominant elements in the images.

Because traditional geometric shapes, such as squares and circles, may have cultural associations, the use of such shapes may not be the best means to represent emotion visually. To improve our visualization representations, we next investigate procedural methods involving texture, pattern and animation, in addition to colour, to visualize emotion. This new approach should avoid cultural associations with specific geometric shapes that may exist.

3.6 CONCLUSION

In our first attempt to create abstract visual representations of emotion, we learned a lot about the choice of visual characteristics and how they contribute to natural understanding and interpretation. We did this by synthesizing work from psychology, art and HCI. Our empirical findings from the SAM were not particularly strong, which tells us that our visualizations were effective at conveying some aspects of emotion, but do not meet our goal of at-a-glance understanding without prior instruction. However, our forced-choice categorical results confirm that we are on the right track with certain visual characteristics chosen for the design of abstract visual representations of emotion. In the next chapter, we show how we evolved EmotiViz to incorporate what was learned with this pilot study.

CHAPTER 4

VISUALLY REPRESENTING EMOTION

4.1 INTRODUCTION

In this chapter, we take a different approach to creating abstract visual representations of emotion. We draw from what we learned from the pilot in Chapter 3 and create animated visualizations that are procedural in nature. Unlike the compositional and algorithmic approach described previously, the visualizations in this chapter are a hybrid of the compositional approach from Chapter 3 and a new procedural approach used to make animated visualizations. We show how we updated EmotiViz to create such visualizations, and the details of two user studies we conducted to demonstrate experimentally that our abstract representations of emotion are interpretable and work for at-a-glance understanding.

4.2 GENERATING VISUAL REPRESENTATIONS OF EMOTION

In Chapter 3, we drew from existing work to create EmotiViz to generate abstract visual representations of emotion; however, we learned through our user study that more work was necessary to create visualizations that could convey emotional states at-a-glance and without prior training. In this sub-section, we describe how we modified EmotiViz.

We decided to take a hybrid compositional and procedural approach to creating visual representations of emotion. Like the compositional approach described in Chapter 3, each emotion quadrant uses a different visualization technique. However, within each quadrant we used a procedural approach to create granular changes within each visualization technique. Also like Chapter 3, we used characteristics of colour theory and geometry to represent emotion. However, to add an additional dimension that could be used to better represent emotion, we decided to use movement, based on movement and dance theory. Because dance movements often convey emotion that is naturally interpretable, we thought this would be a wise choice for our visualizations.

To create visualizations that include movement, we decided to use the LaVizKit toolkit, which was developed by the Interaction Lab at the University of Saskatchewan to create animated visualizations using graphical effects. To create our hybrid compositional and procedural approach, we created a custom visualization based on the graphical effects LaVizKit provides for each compositional approach. Then within each quadrant, we procedurally changed the visualization parameters based on the specific arousal and valence value. Figure 7 shows sample visualizations for each quadrant.

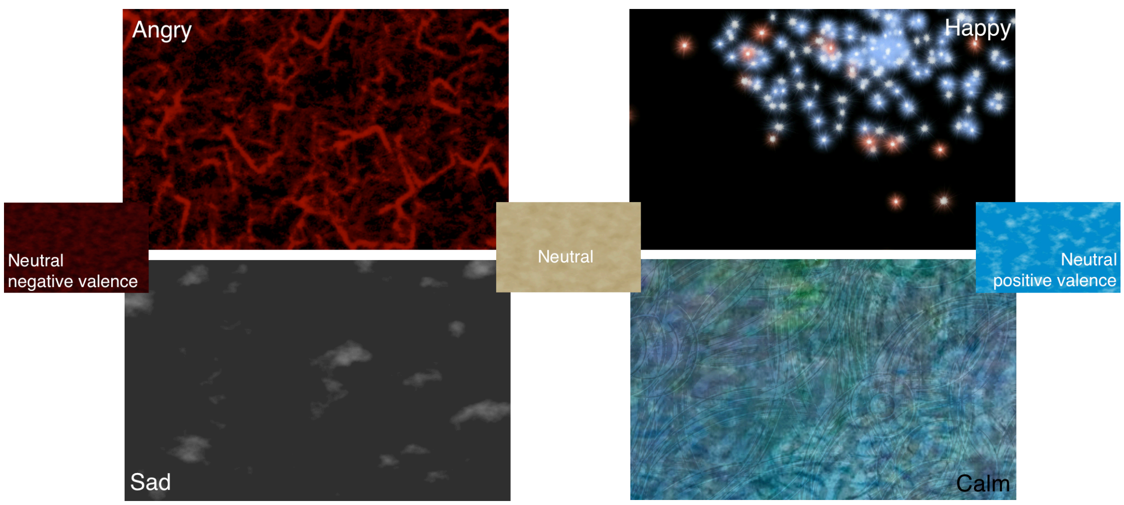


Figure 7 Abstract visual representations of emotion generated by EmotiViz.

For the *negative valence/high arousal quadrant (angry)*, we created a lava visualization. This visualization glows red and appears to shake violently. The effect is an abstract allusion to a hardening lava flow. We varied the colour intensity by valence (based on Valdez and Mehrabian, 1994) and the speed of the effect by arousal (based on Detenber et al., 1998).

For the *positive valence/high arousal quadrant (happy)*, we created a fireworks visualization, which appears as a black screen with explosions of particles of bright colours meant to suggest fireworks in a night sky. The rate of explosions is determined by arousal (based on Detenber et al., 1998) and the direction of the particles after the explosion is determined by valence: the higher the valence, the more directly upward the particles move (based on Boone and Cunningham, 1998).

For the *negative valence/low arousal quadrant (sad)*, we created a fog visualization. This effect appears like thick black or dark grey fog. The fog moves in a downward motion, based on Boone and Cunningham (1998), which suggests that downward movements convey sadness. We varied the arousal by velocity (Detenber at al., 1998) and the valence by colour (Valdez and Mehrabian, 1994).

For the *positive valence/low arousal quadrant (calm)*, we created a water ripple visualization atop a background reminiscent of Monet's palette. The background colours convey a calm feeling according to Valez and Mehrabian (1994). Water ripples appear like droplets on the surface and fade away. The quantity of droplets is determined by arousal (loosely based on Itten, 1970). For Study 3, the size of droplets was determined by valence but we changed this prior to Study 4 such that the size of the droplets are also determined by arousal and the darkness of the droplets and background mask are determined by valence—darker ripples and background convey lower valence (Valdez and Mehrabian, 1994).

For *neutral valence* locations, we created a mist visualization with neutral colour tones. This is also used for the intersection of both axes (neutral arousal and neutral valence). The speed at which the neutral-coloured mist moves is determined by arousal (based on Detenber et al., 1998).

For *neutral arousal* locations, we also used the mist visualization but with varying colours. For negative valence, the mist is black on a red background while the mist is blue on a white background for positive valence (Valdez and Mehrabian, 1994). For negative valence, the mist moves from right to left, while for positive valence, it moves from left to right.

Finally, it is important to note how the visualizations transition. Because the visualizations are created using a parametric toolkit, they transition smoothly along either axis within a quadrant. The visualizations are quite different for each quadrant, so we transition through neutral states (i.e., we fade in and out of the transitioning visualizations to avoid abrupt changes) when we shift between quadrants.

4.3 EVALUATION

Our goal in evaluating the revised EmotiViz is to determine whether our visual representations of emotion convey the intended emotional state to people. Additionally, we wanted to know whether people would be able to interpret them without prior instruction or training, such that they would meet our design goal of being suitable for at-a-glance understanding. We now describe the details of the two user studies we conducted to evaluate the abstract visual representations of emotion produced by the revised EmotiViz.

In Study 3, we wanted to determine whether people could identify *differences* between the emotion representations using our visualizations. In Study 4, we wanted to determine whether people could identify *transitions* in the represented emotion in the visualizations. The animated visualizations used in Study 3 represent a single point in arousal-valence space, whereas in Study 4, they represent movement between 2 points in AV space. Both studies were conducted in a laboratory to ensure consistent viewing context and technology over all participants.

4.3.1 Study 3

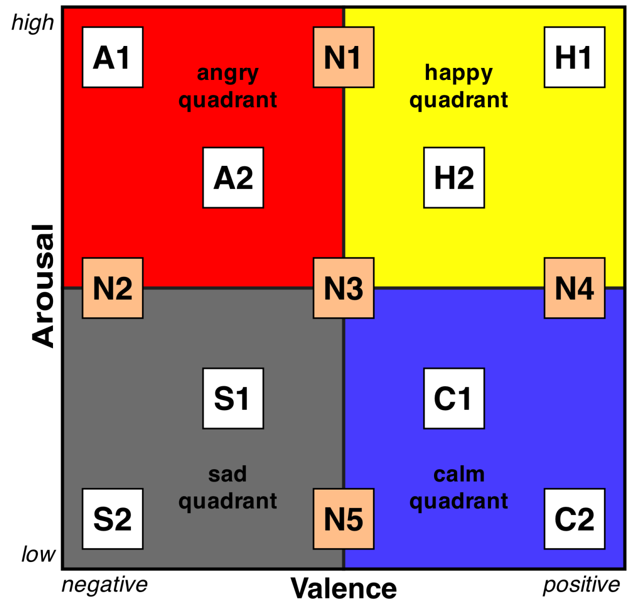


Figure 8 Locations of Study 3 stimuli in AV space.

In Study 3, 39 participants (aged 18-44, mean 25, 9 female) responded to a series of questions to identify what emotions they thought were conveyed by the visualizations. Participants began by completing an informed consent followed by a brief Ishihara Colour Plate Test (1959) to screen out participants who showed colour vision deficiencies (CVD). Participants then completed training using 4 images from a set of emotionally-labeled images from the International Affective Picture System (IAPS) (Lang et al., 2008). We presented IAPS images 6230, 8030, 2722 and 5000 on a black background for 5 seconds each. We used the IAPS images as training because there are normative arousal and valence ratings provided for these images, which we used to screen for outlier participants who did not fall within three standard deviations of the means provided by IAPS. Participants outside of three standard deviations would be removed from the results. However, no participants were removed from our analysis as a result of the IAPS screening process.

After training, participants viewed video clips of the visualizations generated by EmotiViz. We selected representative clips for 13 locations in AV space shown in Figure 8 labeled according to their quadrant (A=angry, H=happy, S=sad, C=calm, N=neutral). These locations included the extreme and mid-points of each quadrant, plus neutral locations on both axes. Participants were asked to determine what emotion the visualization was trying to convey. They responded by rating the arousal and valence values using the SAM (Bradley and Lang, 1994).

Following the SAM ratings, participants categorized the same set of 4 IAPS images and 13 EmotiViz visualizations with 5 categories (angry/enraged, excited/joyful, calm/satisfied, sad/depressed and neutral) based on the 4 quadrants of AV space, similar to Ibanez (2011). In both the ratings and categorization tasks, each of the 13 visualizations was presented for 15 seconds. Participants could re-watch the same clip by clicking a button.

For both the SAM ratings and quadrant categorization, we used a systematic ordering starting from the top left of AV space moving methodically toward the bottom right by moving left to right and top to bottom. We counterbalanced the starting position using a Latin Square to avoid any order of presentation effects.

The study took between 15 and 30 minutes. Participants were given $5 to thank them for their participation. The behavioural ethics board at the University of Saskatchewan approved the experiment protocol.

The experiment was conducted on a Windows 7 computer with a 22” LCD display running at a resolution of 1680x1050. All visualizations were presented in full screen. The system logged all ratings data for subsequent analysis.

4.3.2 Study 4

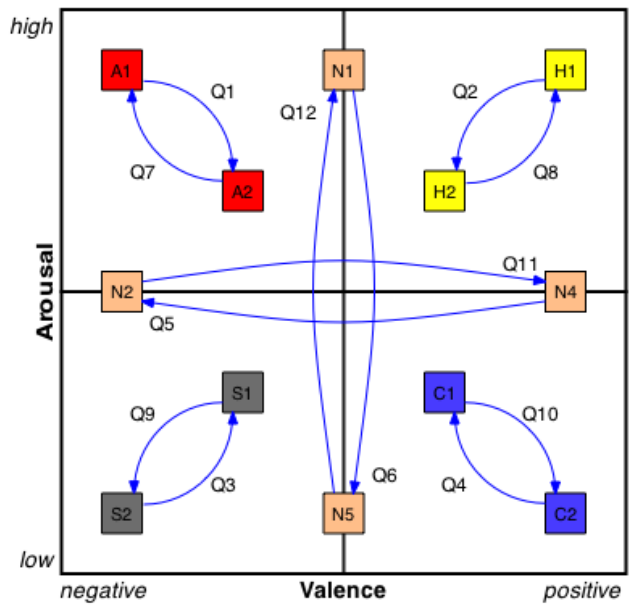


Figure 9 Study 4 stimuli (Q1-Q12).

In Study 3, we evaluated single points in AV space independently. In Study 4, we evaluated transitions between two points in AV space. 24 participants (aged 18-40, mean 25, 9 female, 10 who had participated in 3) watched 25-second videos of visualizations transitioning in both directions between two emotional states within a quadrant and along the neutral axes for both arousal and valence, resulting in 12 representative videos generated from EmotiViz (see Figure 9). Within each quadrant, we selected transitions moving diagonally in AV space between the furthest point from neutral and a point close to neutral. For example, Q1 transitioned from A1 to A2. For neutral locations, we selected transitions moving between negative valence and positive valence with neutral arousal and transitions moving between high arousal and low arousal with neutral valence. After completing an informed consent and a colour vision test, participants viewed the transition videos and were asked to identify whether the change in emotion over time for each of arousal and valence was (a) increasing, (b) decreasing or (c) not changing.

We presented the transitions videos in a single ordering (as described for Study 3), and counterbalanced the starting position using a Latin Square to avoid any effects of order of presentation. The entire study took between 15 and 30 minutes. Participants were given $5 to thank them for their participation.

4.4 RESULTS

We organize our analyses according to our research questions:

- *Can users identify the intended emotion quadrant? (Study 3)*
- *Do participants differentiate between the visualizations in terms of arousal and valence ratings? (Study 3)*
- *Are participants able to identify transitions in visualized arousal and valence within an emotion quadrant? (Study 4)*

4.4.1 Identifying the Intended Emotion Quadrant

In a forced-choice test in Study 3, participants were asked to choose a single category for the visualization from five options: angry/enraged, excited/joyful, calm/satisfied, sad/depressed and neutral. For each visualization, we conducted a chi-square test (df=4) to determine whether one choice of category was made significantly more often than others. The chi-squared test was significant with $p \approx .000$ for every stimulus ($\chi 2$ values: A1-127.8, N1-37.3, H1-127.8, A2-79.8, H2-70.4, N2-26.0, N3-49.3, N4-119.0, S1-23.9, C1-87.5, S2-44.7, N5-61.6, C2-103.9).

Table 6 Frequency of choice of emotion quadrant by stimulus. Italicized text indicates predicted.

	A1	N1	H1	A2	H2	N2	N3	N4	S1	C1	S2	N5	C2
Angry	*36*	1	0	*30*	0	7	0	0	1	0	4	0	0
Happy	2	2	*36*	3	*28*	0	0	2	0	4	0	0	0
Sad	0	5	0	1	1	19	7	0	*11*	1	*24*	3	1
Calm	0	9	1	1	8	4	8	35	15	*31*	6	10	*33*
Neutral	1	*22*	2	4	2	*9*	*24*	*2*	12	3	5	*26*	5

We then checked whether the most frequently selected category matched the predicted category for each stimulus (Table 6). For non-neutral stimuli (those that are not on one of the axes of arousal-valence space), the selected quadrant matched the predicted quadrant for 7 of the 8 stimuli. The only exception was S1, where the predicted category was sad/depressed and the selected category was calm/satisfied.

For neutral valence stimuli, we predicted that participants would select the neutral category rather than one of the four quadrants. For N1, N3 and N5 (neutral valence with varying arousal) the most frequently chosen category was neutral, as predicted. However, participants selected the quadrant for N2 (neutral arousal, negative valence) and N4 (neutral arousal, positive valence) that matched the perceived valence but with low arousal (sad/depressed and calm/satisfied respectively).

These results show that participants were able to accurately identify the intended emotion quadrant for all but 3 of the stimuli, which were identified as a neighboring category in AV space.

4.4.2 Differentiating Visualizations

Means and standard deviations from the arousal and valence ratings from Study 3 are plotted in Figure 10. We conducted Friedman Analysis of Variance by Ranks on both the arousal and valence ratings. Results showed that there were significant differences in the ratings depending on the presented visualization (arousal: F_{12}=277.6, p≈.000; valence: F_{12}=272.1, p≈.000). Because there are 13 visualizations, we present the pairwise comparisons for major (between quadrants) and minor (within-quadrant) differences separately. Pairwise comparisons are made using Wilcoxon signed ranks tests.

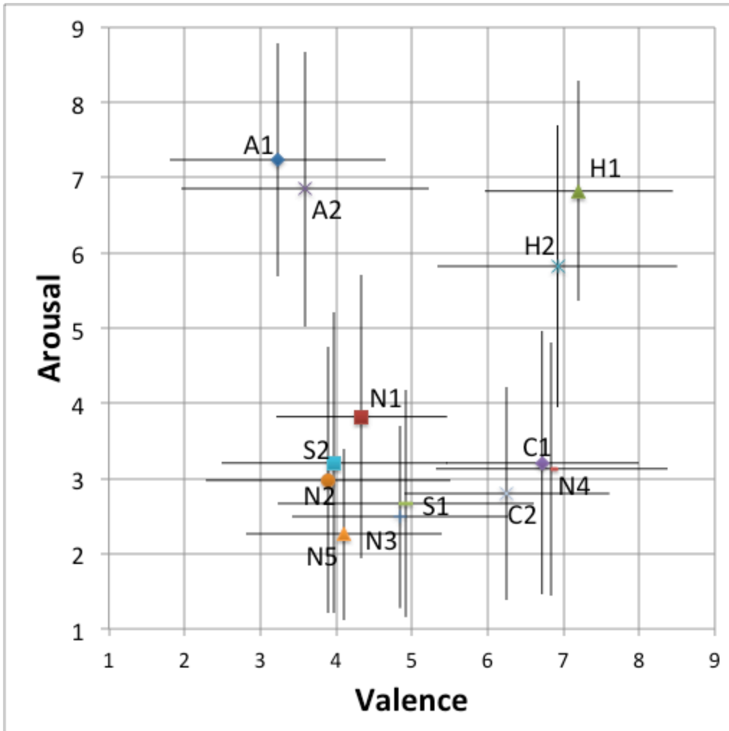


Figure 10 Arousal-valence plot of mean SAM ratings from Study 3. Error bars show standard deviation.

Table 7 p-values for pairwise comparisons between stimuli for arousal. Light shaded cells indicate a comparison of major difference; dark shaded cells indicate a comparison of predicted minor difference; white cells indicate no predicted difference.

	A1	**A2**	**H1**	**H2**	**S1**	**S2**	**C1**	**C2**
A1	-	.494	.458	**.028**	**.000**	**.000**	**.000**	**.000**
A2	-	-	.954	.131	**.000**	**.000**	**.000**	**.000**
H1	-	-	-	.146	**.000**	**.000**	**.000**	**.000**
H2	-	-	-	-	**.000**	**.000**	**.000**	**.000**
S1	-	-	-	-	-	.295	.233	.716
S2	-	-	-	-	-	-	.884	.494
C1	-	-	-	-	-	-	-	.407
C2	-	-	-	-	-	-	-	-

Using these pairwise comparisons, we look at differences between stimuli with major variations in arousal (e.g., A1 to S2) in Table 7. Significant differences were found for all 16 between-quadrant differences. Next, we look at differences between stimuli with minor variations in arousal (e.g., A1 to A2, A1 to H2). Only A1-H2 was significant in this case.

4.4.2.1 Valence

Table 8 p-values for pairwise comparisons between stimuli for valence. Light shaded cells indicate a comparison of major difference; dark shaded cells indicate a comparison of predicted minor difference; white cells indicate no predicted difference.

	A1	A2	H1	H2	S1	S2	C1	C2
A1	-	.282	**.000**	**.000**	**.000**	.257	**.000**	**.000**
A2	-	-	**.000**	**.000**	**.013**	.954	**.000**	**.000**
H1	-	-	-	.684	**.000**	**.000**	.450	.069
H2	-	-	-	-	**.000**	**.000**	.727	.159
S1	-	-	-	-	-	**.015**	**.000**	**.001**
S2	-	-	-	-	-	-	**.000**	**.000**
C1	-	-	-	-	-	-	-	.289
C2	-	-	-	-	-	-	-	-

Using pairwise comparisons, we look at differences between stimuli with major variations in valence (e.g., A1 to H1) in Table 8. All of the 16 potential major between-quadrant differences showed significant differences in the pairwise comparison. Next, we look for differences between stimuli with minor variations in valence (e.g., A1 to A2). Two of these cases (A1-S1, S1-S2) were significant. In addition, the S1-A2 comparison was significantly different although it was not predicted to be so as A2 and S1 represented the same valence, but with different arousal.

4.4.2.2 Neutral

Table 9 Stimuli differences for neutral stimuli. * indicates significant with p≈.000, # indicates significant with p < .05 and empty cells indicate p=1.00.

	Arousal					Valence				
	N1	N2	N3	N4	N5	N1	N2	N3	N4	N5
A1	*	*	*	*	*	#		#	*	
A2	*	*	*	*	*			#	*	
H1	*	*	*	*	*	*	*	*		*
H2	#	*	*	*	*		*	*		*
S1	#						#		*	
S2					#				*	
C1					#	*	*	*		*
C2	#					#	*	#		*
N1	-		#		#	-			*	
N2	-	-				-	-		*	
N3	-	-	-			-	-	-	*	
N4	-	-	-	-	#	-	-	-	-	*
N5	-	-	-	-	-	-	-	-	-	-

Table 9 shows a matrix of differences between stimuli for both arousal and valence. For arousal, there were differences between most neutral stimuli and non-neutral stimuli with positive arousal (e.g., A1 and N3, N5 etc.). For valence, there were differences between most neutral stimuli and non-neutral stimuli with positive valence (e.g., N2 and H2, C1, etc.).

4.4.3 Identifying Transitions in Visualizations

Results from Study 3 showed that participants could identify the intended quadrant for an emotional visualization and could differentiate between visualizations using ratings of arousal and valence for major variations (between quadrants), but have trouble differentiating between levels of the same visualization (within a quadrant). In Study 4, we looked to see whether participants could interpret changes in the levels of a visualization when these changes are presented dynamically in a video transitioning between two points within an emotion quadrant. Participants selected a category (increase, decrease, no change) for arousal and valence.

Participants rated the perceived change in emotion for 12 stimuli (see Figure 5). They identified whether the change during the clip was increasing, decreasing or not changing for each of arousal and valence. For each of the stimuli, we conducted a chi-square test (df=2) for both arousal and valence, to determine the most frequently chosen option. Table 10 shows the frequency of responses by stimuli and Table 11 summarizes the results.

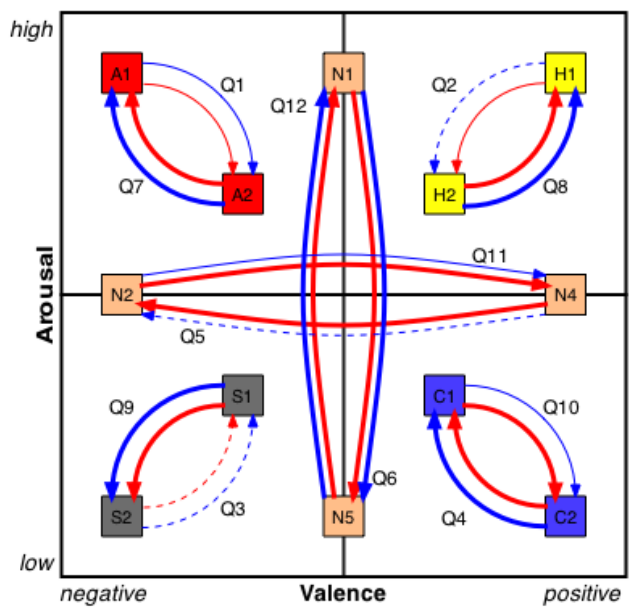


Figure 11 Study 4 stimuli. Each line represents the direction of transition in the stimulus clip (blue for arousal, red for valence). Dotted lines indicate no statistically significant difference; solid lines indicate significant differences; thick solid lines indicate significance matching the predicted category.

Table 10 Frequency of responses by stimuli.

Stimulus	1	2	3	4	5	6	7	8	9	10	11	12
Arousal												
Increase	15	11	9	16	9	0	22	21	0	8	6	15
Decrease	7	9	9	4	4	16	1	0	20	11	8	3
No change	2	4	6	4	11	8	1	3	4	5	10	6
Valence												
Increase	3	18	6	5	1	3	1	13	2	14	16	2
Decrease	16	1	12	15	22	5	21	3	16	3	2	1
No change	5	5	6	4	1	16	2	8	6	7	6	21

The chi-squared tests showed significant results for the most frequently chosen option for many of the stimuli, but we must also check whether the chosen category matches the predicted category.

For stimuli Q1 through Q4 (where the direction of movement was toward the centre of AV space), only Q4 was both statistically significant and the most frequent category matched the predicted category. However, for Q7 through Q10 (where the direction of movement was away from the centre of AV space), the most frequently chosen option matched the predicted category for both arousal and valence and were also statistically significant in all cases except for Q10 (see Table 11). Similarly, all neutral stimuli matched their predicted categories and were statistically significant in 6 of 8 cases.

Table 11 Chi-squared test results for Study 4. Bold predicted category text indicates the predicted category matched the most frequently selected category.

Stimulus	Arousal			Valence		
	χ2 value	**Sig.**	**Exp. Cat**	**χ2 value**	**Sig.**	**Exp. Cat**
Q1	10.750	**0.005**	Decrease	12.25	**0.002**	Increase
Q2	3.250	0.197	Decrease	19.750	**0.000**	Decrease
Q3	0.750	0.687	Increase	3.000	0.223	Increase
Q4	12.000	**0.002**	**Increase**	9.250	**0.010**	**Decrease**
Q5	3.250	0.197	**No change**	36.750	**0.000**	**Decrease**
Q6	16.000	**0.000**	**Decrease**	12.250	**0.002**	**No change**
Q7	36.750	**0.000**	**Increase**	31.750	**0.000**	**Decrease**
Q8	32.250	**0.000**	**Increase**	6.250	**0.044**	**Increase**
Q9	28.00	**0.000**	**Decrease**	13.000	**0.000**	**Decrease**
Q10	2.250	0.325	**Decrease**	7.750	**0.021**	**Increase**
Q11	1.000	0.607	**No change**	13.000	**0.002**	**Increase**
Q12	9.750	**0.008**	**Increase**	31.750	**0.000**	**No change**

4.4.4 Summary of the results

Our results can be summarized into the following points. Participants were able to:

1. Identify the intended emotion quadrant using forced-choice categorization.

2. Distinguish differences between stimuli from different quadrants for arousal and valence.

3. Distinguish differences in neutral stimuli for both arousal and valence.

4. Identify change in arousal and valence in transitioning visualizations within emotion quadrants (away from neutral) and along the neutral axes.

Participants had trouble distinguishing minor differences in arousal and valence for most stimuli within quadrants.

4.5 DISCUSSION

We now discuss the results from the two user studies. We first look at the details of the results to draw conclusions about how people interpret the abstract visualizations of emotion. Finally, we explore the high-level implications of creating abstract visual representations of emotion.

4.5.1 Interpreting Abstract Visualizations of Emotion

Results from Study 3 showed that participants could identify the intended quadrant for all stimuli except for S1. The evidence suggests that S1 expresses too much valence because it was rated as calm/satisfied rather than sad/depressed. The SAM ratings support this – the mean SAM valence rating was 4.92, which is slightly on the negative side of neutral valence (5.0). Our results also showed that participants are able to identify differences between major variations of stimuli. All of the major between-quadrant differences were significant for both arousal and valence.

The neutral stimuli were not found to be significantly different from one another based on the SAM ratings. Looking at arousal differences, there were no significant differences between steps along the arousal axes with neutral valence (i.e., N1, N3 and N5). The relative order of their mean arousal ratings matched the predicted order; however, arousal ratings were all clustered below neutral arousal (5.0). The results also show similar problems with valence. We attribute these problems to the interaction of the arousal and valence axes. Although these axes are theoretically orthogonal, there is evidence that they are not entirely independent. Lang et al. (1993) had difficulty finding images that represent the extreme regions of calm/satisfied quadrant. It seems that if an image is truly unpleasant, it cannot also be calm, suggesting some interplay between these two axes.

Results from Study 3 showed that participants had problems identifying differences between different levels of the visualizations (within quadrants) using the SAM scale. However, given the results of Study 4 (discussed shortly), we do not believe this is strictly a problem with the stimuli but rather a problem with the scale used. Our participants tended to avoid extreme values in the SAM scale, and likely did not interpret distances between different gradations of the scale equally. This suggests that for each of the two stimuli per quadrant, people tended to cluster their responses both away from neutral and away from the extreme value, whether it was high or low. This clustering of ratings makes it unlikely to find statistical differences between the means. We may have been better able to show a difference between minor variations of stimuli had we asked a forced-choice categorical question to identify, for example, which of A1 and A2 expresses more anger.

This interplay between the axes may also explain why in some cases, relative arousal or valence values are reversed. For example, the relative arousal is the reverse of what was predicted for S1 and S2 (S2 should be rated lower). In this case, increasing arousal was mapped to faster movement and increasing valence was mapped to lighter colours. So the cloud effect is darker in S2 than in S1, but S1 moves faster than S2. The reversal of ratings may be due in part to some interaction between movement and colour selection.

Study 4 showed that participants were able to identify differences when the visualizations transition from one point to another point within the same quadrant. Participants were able to detect increases, decreases and no change in both arousal and valence. Transitions starting from locations near the centre of arousal-valence space moving toward the outer edges worked better than the reverse direction. It is possible that change blindness (Levin and Simons, 1997) is a factor that contributes to participants' inability to detect certain types of change since the transitions were noticed in one direction but not the reverse. The ability to detect and interpret change might be harder when moving from weak to strong stimuli than from strong to weak stimuli.

Overall, our results showed that we successfully created abstract representations of emotion for all four emotion quadrants, in addition to neutral. Our evaluation showed that people are able to interpret the abstract representation. Participants were told how to use the SAM scale, but were not told how to interpret any of the visualizations or effects used within them. Unlike information art (e.g., where the size of the sun indicates the quantity of happiness in an individual or group), our visualizations do not require explanation or prior training. In addition, our visualizations were quickly interpretable; with only a 15-second clip of each visualization, participants were able to interpret the emotion we intended to convey. Most importantly, our visualizations work without training, prior instruction, or extended exposure to the visualizations. The visualizations generated by EmotiViz are the first abstract visualizations of emotion that have been experimentally shown to be naturally and widely interpretable without prior training.

4.5.2 Using Animation in Visual Representations of Emotion

We chose to use animation in our visual representations of emotion because we believe movement is naturally interpretable. Similar to research by Boone and Cunningham (1998) that shows that children easily understood emotions conveyed in dance, our visualizations were based on characteristics of perception that we believe are naturally understood.

4.6 CONCLUSION

In this chapter, we took what we learned from Chapter 3 to create animated abstract visual representations of emotion that are suitable for at-a-glance understanding, and work without prior training. We found that people could understand the emotion quadrant (from Russell's circumplex) that we predicted. Additionally, we showed that people can interpret transitions in the visual representations – especially if the transitions are toward extreme values of arousal and valence. Overall, this chapter makes 3 research contributions. First, we have created abstract visual representations of emotion that can be used in digital environments to represent and convey emotion. Second, we demonstrate that it is possible to create naturally interpretable visual representations. Finally, we show that it is possible to create visual representations that can be interpreted without prior instruction.

In the next chapter, we apply these visual representations of emotion in a biofeedback application. The visualizations can be used to convey emotion and help people self-regulate how they feel while conducting a performance task. We do this to demonstrate the utility and wide range of practical uses for the abstract visual representations of emotion. Furthermore, we use this as evidence in support of their at-a-glance understanding, to further demonstrate they are usable without prior instruction in a real-world task.

CHAPTER 5

EVALUATION OF AN AMBIENT BIOFEEDBACK DISPLAY

5.1 INTRODUCTION

In Chapters 3 and 4, we developed a method to create visual representations of emotion that are interpretable without prior instruction. This means that the visualizations are suitable for understanding at a glance. We previously evaluated these visualizations in controlled experiments to determine whether they conveyed the intended emotional state. The next step is to use the visualizations in an interactive system. We feel that the abstract representation of emotion has many applications, including: enhancing computer-mediated communication; displaying characteristics of group rapport in teamwork settings; and helping users to self-regulate their emotional and physiological state through biofeedback. In all of these examples, the visualizations would be best displayed on an ambient display. In this Chapter, we describe the design and evaluation of two ambient displays for representing emotion. We chose to apply our designs in a biofeedback task, in order to eliminate the potential confounding factors of using a collaborative task.

Biofeedback has been used for a variety of purposes to help people regulate their physiology. According to the Association of Applied Psychophysiology and Biofeedback, biofeedback is defined as: *"Biofeedback is a process that enables an individual to learn how to change physiological activity for the purposes of improving health and performance."* (2011) For our biofeedback task, we manipulated arousal and measured memory recall performance to find a range of arousal for optimal task performance, as described by the Yerkes-Dodson Law (Yerkes and Dodson, 1908; Hebb, 1955). We used ambient biofeedback displays to help people regulate their physiological arousal and overcome the arousal manipulation. The biofeedback display used the visual representation of emotion to guide people to the desired level of arousal.

In this chapter, we describe the design and evaluation of an ambient biofeedback display. We first discuss the related work. Next, we describe how we designed and built two ambient displays for our biofeedback task. We then look at our experimental design and results, followed by a discussion of the results.

5.2 RELATED WORK

In this section, we provide an overview of the related literature related to biofeedback displays for improving performance in cognitive-based work. First we describe the effect of task performance and memory on physiological arousal. We used this information to guide the design of the experiment. Second, we explore ambient displays and how they can be used to influence human behaviour. This informed the design of our ambient display for biofeedback.

5.2.1 Arousal and Task Performance

At the turn of the 20th century, Yerkes and Dodson developed a model for describing the relationship between physiological arousal and task performance (Yerkes and Dodson, 1908). While Yerkes and Dodson experimented with lab mice, it was later reproduced with chicks (Cole, 1911) and kittens (Dodson, 1915). Broadhurst (1957) reproduced their results using a more robust design and a larger number of participants (lab rats). Teigen (1994) provides a good overview and history of the original Yerkes and Dodson work and the reformulation into what is now referred to as the Yerkes-Dodson Law.

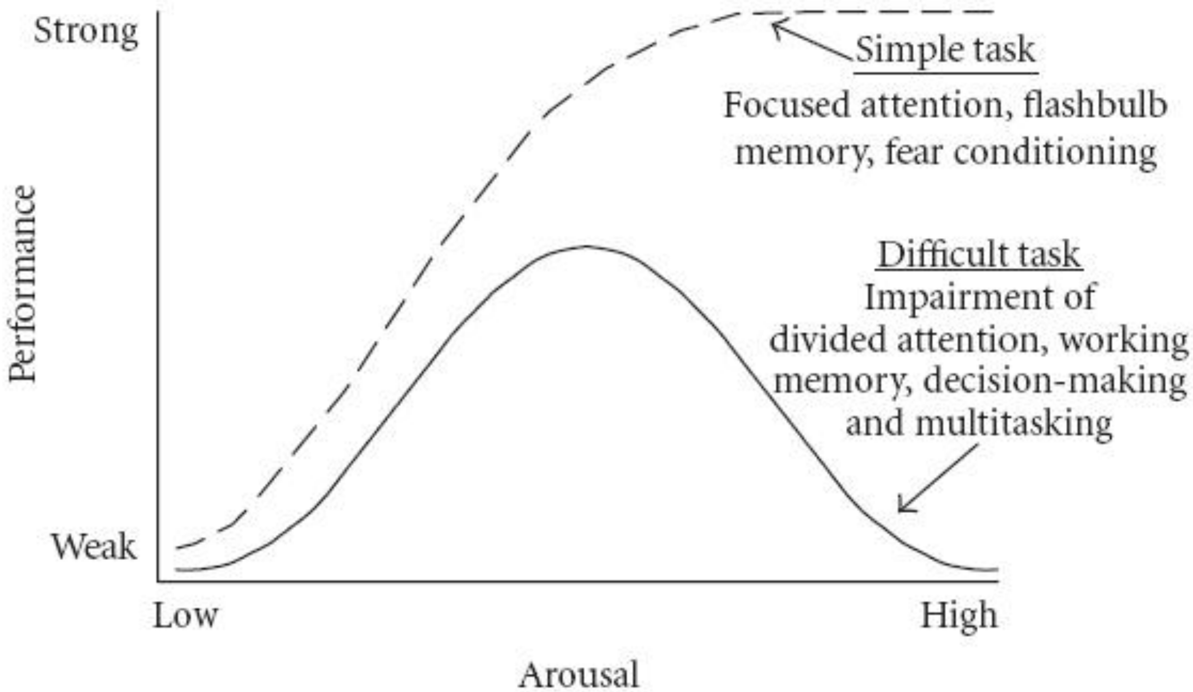


Figure 12 The Hebbian version of the Yerkes-Dodson Law. (Public domain; from Wikipedia, http://en.wikipedia.org/wiki/Yerkes%E2%80%93Dodson_law)

Hebb (1955), working independently and without citing the original Yerkes and Dodson work, introduced the inverted U to describe the relationship between arousal and performance (see Figure 12). This led to researchers adapting the original Yerkes and Dodson experiment to use the terms arousal and performance. Ultimately, the Yerkes-Dodson Law became prominent and referred to the combined work of Yerkes and Dodson with the more recent work of Hebb.

Today, the Yerkes-Dodson Law is used to describe a curvilinear relationship between performance and arousal. For simple tasks, an increase in arousal causes an increase in performance, until arousal flattens the performance arc. However, for difficult tasks, an increase in arousal beyond a certain point causes a decrease in performance. This causes an inverted U-shape relationship of performance to arousal. Thus, the Yerkes-Dodson Law suggests there is a range of physiological arousal that supports optimal task performance for sufficiently difficult tasks.

The Yerkes-Dodson Law is supported by a variety of evidence with human subjects for biofeedback. Bregman and McAllister (1982) used monetary payments to manipulate motivation (arousal) for increased performance on a biofeedback task involving increasing finger temperature. Wu et al. (2010) used a virtual reality stroop task to find an optimal level of arousal.

5.2.2 Effect of Arousal on Memory

There is a variety of work that has assessed the effects of arousal on memory performance. Esenck (1976) provides an excellent overview. He reviewed literature assessing arousal, learning and memory correlates and differentiates the effect arousal has on memory storage versus retrieval. Isaacowitz et al. (2000) reasoned ways in which emotion and cognition are connected. They suggest ways in which changes in affect influence performance on cognitive tasks. More recently Gray (2008) provided a model for understanding how multiple brain systems that mediate emotion and cognition overlap. Because of this overlap, there is reason to believe there is neurobiological evidence that emotion affects cognition.

This recent neurobiological work supports evidence collected by psychology researchers over the last 60 years. Isen et al. (1978) conducted two studies looking at positive mood (valence) and memory recall. They found participants in a positive mood responded more positively to evaluations of products they owned, and were better able to recall positive material in memory. Bradley et al. (1992) demonstrated that only arousal has an effect on memory performance – and not valence. They found that IAPS pictures rated as highly arousing were remembered better. Similarly, Shorot and Phelps (2004) found that neutral words were forgotten faster than arousing words. Maltzman et al. (1966) found high arousal words were recalled better compared to low arousal words on both immediate recall and 30-minute delayed recall tests. Finally, Sherwood (1965) found memory recall performance highest under low arousal; they found no evidence to contradict or support the theory that performance is best at intermediate levels of arousal.

5.2.3 Ambient Displays and Ambient Influence

In the previous subsection, we showed that there were levels of arousal that yield optimal performance. We now provide an overview of using ambient influence to influence human behaviour with the goal of using this to provide a user with feedback so they can self-regulate their physiological state. While we could provide this type of biofeedback in an intrusive manner, the nature of biofeedback (i.e., always present, demands attention) suggests that using an ambient display to deliver this feedback would be appropriate.

The concept of ambient displays grew out of Mark Weiser's seminal work, *The Coming Age of Calm Technology* (1996). Since then, a variety of ambient displays have been developed that convey information using an ambient channel. Ambient displays have used a variety of techniques to convey information and vary greatly in their utility and purpose. Examples of this include:

- Hello.Wall, which uses lights to convey awareness information in the periphery (Prante et al., 2003).
- Breakaway is a sculpture that encourages office workers to take breaks (Jafarinaimi et al., 2005).
- DiMicco et al. created visualizations that allowed viewers to see who was contributing to a group discussion (2004).

More recently, ambient displays have been used to influence behaviour in subtle ways. Kim et al. (2008) created Meeting Mediator and found that it shortened individuals' speaking time and reduced speech overlap. In an evaluation of Breakaway (Jafarinaimi et al., 2005), the authors found that the display was able to encourage positive change in behaviour. Similarly, Consolvo et al. (2008) found that participants with an awareness display of their daily physical activity were better able to maintain their physical activity, while the activity level of those without the display dropped off. By using ambient awareness, these works were able to influence behaviour, and in many cases, they were able to do so without participants being aware of their own change. Balaam et al. (2011) influenced nonverbal behaviour associated with rapport (such as interactional body language) using an ambient display without participants being aware of their change. Rogers et al. (2010) logged data of participants change in behaviour; they found that the data showed a significant change even though participants reported no change.

There is sufficient evidence that ambient displays can influence a variety of behaviour, including physical (Consolvo et al., 2008; Jafarinaimi et al., 2005; Rogers et al., 2010) and social group behaviour (Balaam et al. 2011). Furthermore, many of these studies have shown this is possible without participants' awareness. There is a link between lack of knowledge of a behavioural change and the type of technology used. Because the displays are ambient, people are often only aware of them in their periphery. For example, Birnholtz et al. (2010) found that people noticed more information on a peripheral awareness display than on a standard on-screen window even though they attended to the peripheral display less often.

The types of applications for ambient displays to date has influenced behaviour in a variety of subtle ways. As far as we aware, there has been no research into the specific design and use of an ambient display for biofeedback purposes. Thus, although we cannot draw from previous work in our specific problem space, we can use the principles from the design of ambient displays in other domains to guide the development of an ambient display for biofeedback.

5.3 DESIGNING AMBIENT DISPLAYS

We designed two types of ambient displays. The first display was a physical display made of plexiglass, which we refer to as the peripheral display. The second display was an immersive display that made use of the walls in the corner of a room. We refer to this as the immersive display.

5.3.1 Peripheral Display

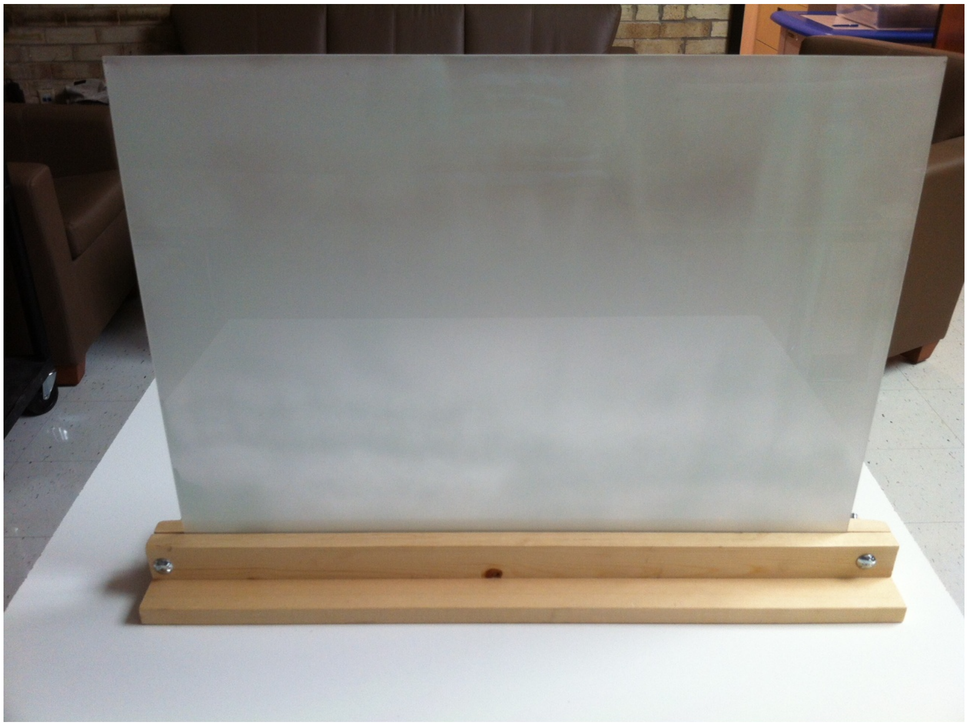


Figure 13 Peripheral display.

We built a peripheral display (Figure 13) capable for use as a surface to hold an image from a projector. We used a 24" x 18" x 1/4" piece of plexiglass coated with Rustoleum semi-transparent frosted glass finish. This was applied to both sides of the plexiglass. With this coating, a projection from one side of the plexiglass would appear on both sides. We then built a simple wooden stand to hold the plexiglass upright.

5.3.2 Immersive Display

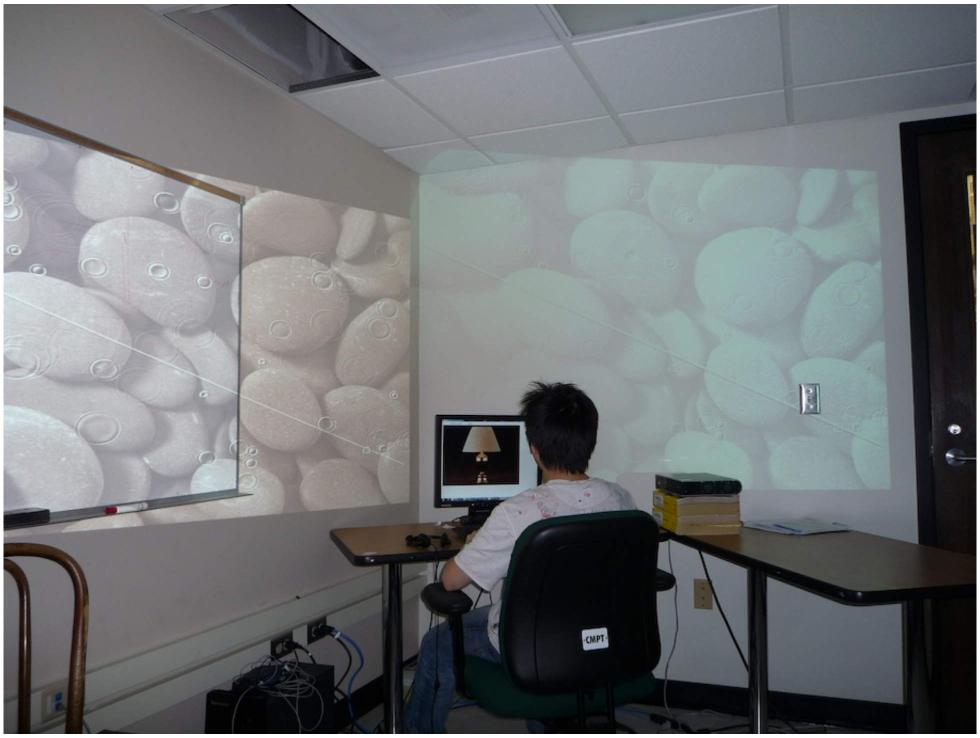


Figure 14 Immersive display.

We used the walls in the corner of a room as our immersive display (Figure 14). This did not require any construction. We placed two projectors at the rear of the room and projected concurrently into the corner. One projector was aimed at the left wall while the second was aimed at the right wall. The overlap between the projectors appeared in the corner.

5.4 EXPERIMENT

We now describe the experiment we conducted to evaluate the ambient displays. This experiment was designed to help us evaluate whether our visual representations of emotion could be used in a biofeedback task on an ambient display. We first describe the tasks, the visualizations used on the ambient displays, the conditions, the measures, and the procedure used in the study. Finally, we explain the data analyses.

5.4.1 Tasks

We now describe the two tasks used in our experiment.

5.4.1.1 Jigsaw Task

In the first task, participants completed a jigsaw puzzle consisting of 6 large jigsaw pieces. The jigsaws used images from IAPS (a database of photographs commonly used in emotion research, which have been shown to elicit a known response; Lang et al., 2008), and were 1024x768 pixels. The jigsaw pieces could be dragged around the screen using the mouse. When dropped in the correct place (with a small pixel offset), the pieces snap to the grid and are no longer movable. At the beginning of each puzzle, the IAPS image appeared (Figure 15) in its correct form on the screen for 5 seconds while a sound played on the participant's headphones. The sounds were from IADS (a database of sounds commonly used in emotion research, which have been shown to elicit a known response; Bradley and Lang, 2007). After the puzzle was completed, the correctly aligned IAPS image appeared again for 5 seconds while the same sound played on the headphones.

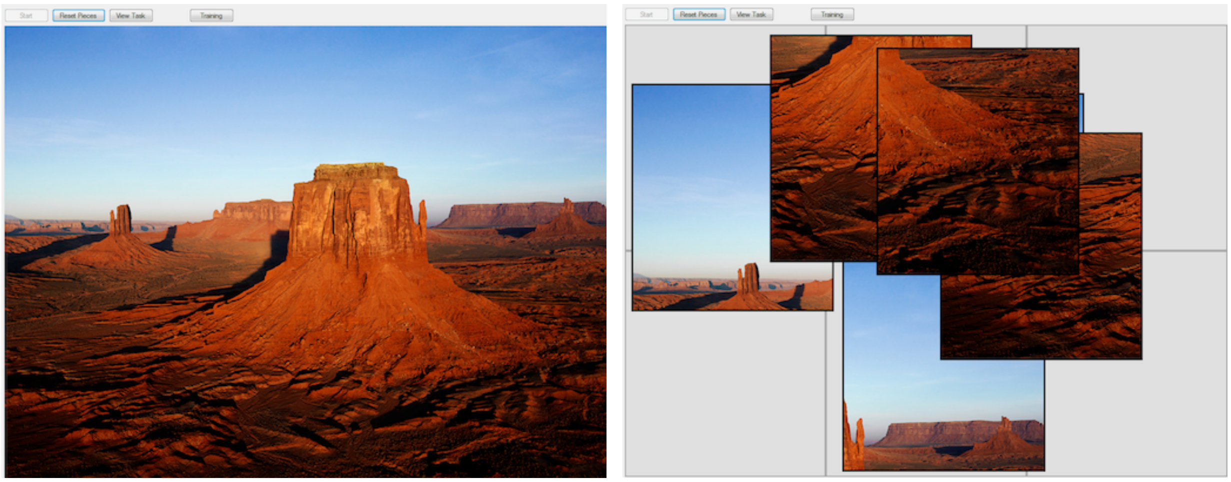


Figure 15 Jigsaw Puzzle task. Initial image exposure (left) and scrambled jigsaw image (right).

30 images and sounds were selected from IAPS (Lang et al., 2008) and IADS (Bradley and Lang, 2007) based on their arousal values. We selected images and sounds within 3 groups of arousal: high, neutral, and low (see Appendix C for the images and sounds selected). For example, one of the images selected in the high arousal category was a downhill ski jumper at the top of a ski jump while the sound was people screaming with excitement on a rollercoaster. In the neutral category, an image of a sunset was selected with a sound of a cat. In the low arousal category, an image of an empty pool was selected with a sound of a person yawning.

Stimuli in the low category were in the range of 1 to 3.5. The neutral category contained stimuli within the range of 4 to 5.5. Finally, the high category had a range of 6.5 to 7.5. We balanced valence so that a comparable proportion of positive and negative stimuli (both images and sounds) were presented within each of the 3 arousal categories. For example, we selected a graphic picture of a person after a car accident (negative valence) and a picture of skydivers (positive valence) in the same high arousal category.

5.4.1.2 Iconic Memory Task

In the second task, participants completed a test of their iconic memory. Iconic memory is a component of the visual memory system, and is a very brief, but high-capacity memory store. George Sperling (1960) was the first to investigate whole and partial report of iconic memory. In his experiments, participants were first asked to fixate on a point. Then participants were presented with characters in a 3x3 or 3x4 array for 50 ms. In the whole report condition, participants were asked to recall as many characters in the correct order as possible. Sperling found that participants were able to recall 3-5 of the 12 characters in whole report.

In our memory test, we used a 3x4 grid (see Figure 16). The entire test was completed on a PC. Participants were instructed to remember and recall as many letters as possible. If they could not remember a letter separating two letters they do remember, they were asked to place a space between the letters. Before the letters appeared, we placed a crosshair over the centre of where the letters would appear to help focus participants.

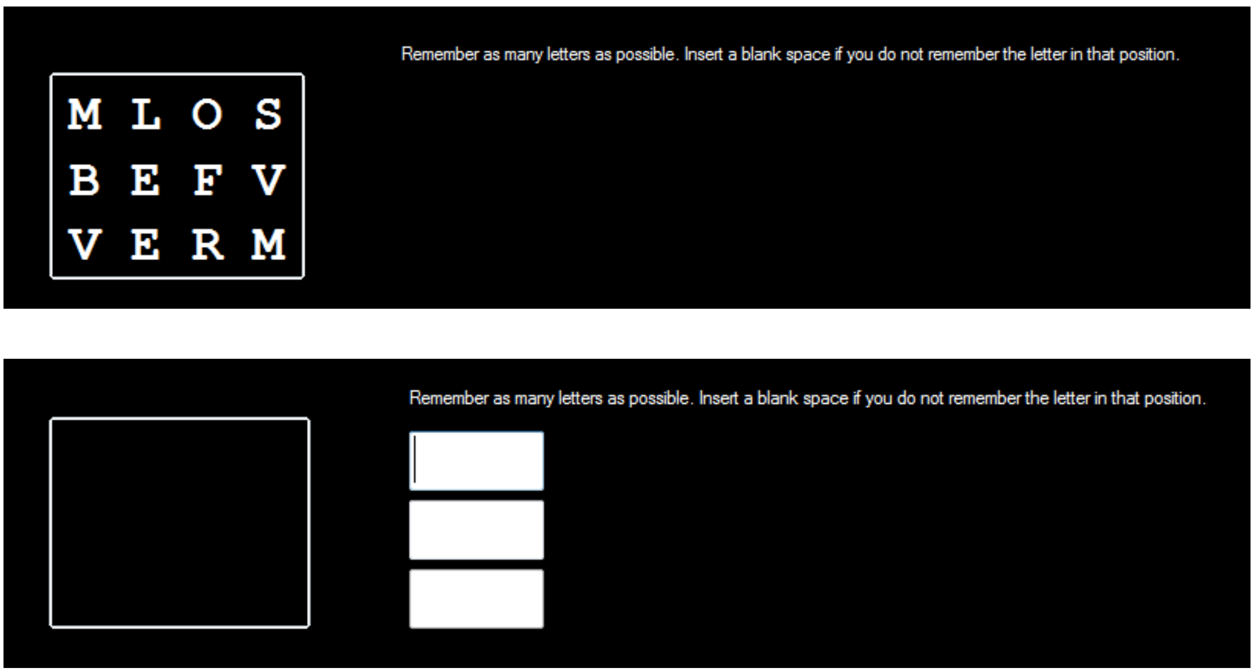


Figure 16 Iconic memory test. Step 1, letters appear (above); step 2, letters disappear and text entry appears (below).

5.4.2 Biofeedback Visualizations

Throughout both the jigsaw and iconic memory tasks, we presented a visualization that represented the intended physiological arousal state that we wanted participants to target. To visualize the intended physiological arousal, we used a single visualization from EmotiViz. We used the water ripples visualization and varied the speed of the water ripples to match the desired physiological arousal. We also changed the background of the water ripples visualization from one reminiscent of Monet's palette to a more neutral riverbed, to allow for representation over the full range of arousal. We decided to use a single visualization for the display so it was visually consistent and less likely to cause distraction with dramatic changes in the type of visualization used.

The display showed a visualization that represented the intended physiological arousal of the participant. For example, if we wanted participants to increase their arousal, the visualization spawned water droplets more frequently. Because of the increased speed, it also meant there were more water droplets visible. When we wanted participants to decrease their arousal, the visualization displayed water droplets less frequently. This meant there were fewer water droplets visible at any given time.

In all cases, the biofeedback display presented the arousal level intended to neutralize the effect of the IAPS and IADS arousal manipulations. With high arousal level, the display presented a visualization to guide people to calm their physiological arousal. In the neutral level, the display presented a visualization to keep people in a neutral state. And in the low arousal level, the display presented a visualization to guide people to increase their physiological arousal. The visualizations were necessary to guide people to the ideal level of physiological arousal so they could perform the iconic memory task consistently despite the manipulation of arousal through the IAPS images and IADS sounds in the jigsaw task.

5.4.3 Conditions

To determine how the design of an awareness display affects user performance and self-regulation of emotion, participants completed the tasks in 3 display conditions.

The first condition was the control condition. Participants did not have any feedback or awareness of their intended physiological arousal.

The second condition used the peripheral display. The intended physiological arousal appeared on the peripheral display placed directly to the left of the computer's primary LCD. A projector located on a table nearby projected onto the peripheral display to provide the feedback.

The third condition used the immersive display. The intended physiological arousal appeared on the two walls the participant faced. Two projectors located behind the participant projected onto the walls.

The ordering of the presentation of the display conditions was counter-balanced using a Latin Square (three orderings).

5.4.4 Measures

To determine whether there is an optimal range of arousal for task performance, we used the iconic memory task. We used the number of letters recalled correctly for each trial to determine this.

To assess participants' reaction to the IAPS and IADS stimuli, we used the self-assessment manikin (SAM) (Bradley and Lang, 1994) to measure arousal and valence. We used the SAM in the same way we used it in the past (see Chapters 3 and 4).

5.4.5 Procedures

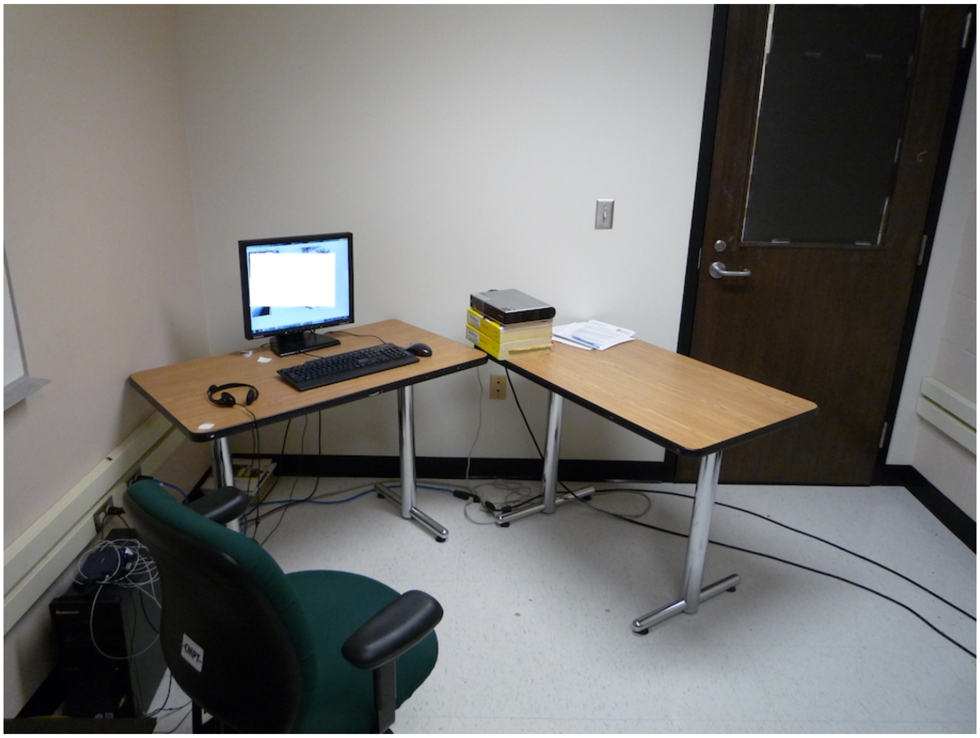


Figure 17 Experimental room setup.

We had 12 participants (4 female) run our study. They sat at a Windows 7 PC and a 22" LCD monitor facing the corner of a small room (Figure 17). We told participants that they were participating in an experiment to determine whether people can use visualizations of physiological arousal to regulate their own arousal to perform tasks optimally.

We began by having participants complete the informed consent form. Next they ran a training exercise to become familiar with the iconic memory test. After completing 10 iconic memory tests, we provided participants with the remaining instructions. This included an explanation of the self-assessment manikin (SAM), arousal and valence.

Once the experiment began, participants alternated between the two tasks (jigsaw and iconic memory). After the jigsaw puzzle, participants completed the SAM to indicate how they currently feel. Next, participants completed the iconic memory test 5 times.

Overall, each participant completed 30 trials (each trial: 1 jigsaw, 1 SAM for arousal and valence, and 5 iconic memory tests). The trials were broken into blocks of the 3 arousal levels described previously (low, medium, high), with 10 puzzles in each arousal level. Everyone viewed the puzzles in the same order, in increasing order of arousal. Through pilot testing, we determined that the arousal manipulation worked whether we did it in increasing or decreasing order. Additionally, each participant completed this over the course of 3 days with 1 of the 3 different display conditions presented each day.

After each session, participants completed a post-condition questionnaire. On the final day, participants also completed a post-study questionnaire.

5.4.6 Data Analyses

We analyze our data in 4 major sub-sections. In the first two sub-sections, we analyze the quantitative data from the self-report of arousal and the performance of the iconic memory test. Here, we first present the data by trial. For each trial, we report 1 self-report of arousal and valence and the sum of the 5 tests of the iconic memory task. We then analyze this same data by grouping the data from the 30 stimuli into their arousal levels (low, neutral, high) to give us 10 stimuli per level. This gives us 10 data points of self-reported arousal and 50 trials of the iconic memory test per arousal level. In the final two sub-sections, we look at the results of the post-condition and post-study questionnaires. We analyze the quantitative data of the questionnaires using measures of frequency of response. For the qualitative data, we report the interesting long-answer responses participants made on the questionnaires.

5.5 RESULTS

We now present the results of the experiment. First, we show the effects of the arousal manipulation from the results of the self-report of arousal (SAM rating). Second, we describe the effects of the arousal manipulation on performance, as shown by the results of the iconic memory test. Finally, we discuss the results of the post-condition and post-study questionnaires.

5.5.1 Self-Report of Arousal

In this sub-section, we show the results of the self-report of arousal data (SAM rating). Specifically, we focus our analysis on the arousal measure to show the effect of the arousal manipulation in the jigsaw puzzles. This was done to validate the effect of the stimuli (IAPS and IADS) and to gauge the effect of the different biofeedback displays on self-regulation. We first show there is a habituation effect of the stimuli. As a result, we then explore the results by looking at the first condition to which participants were exposed. We do this by first presenting the results by trial and then group by arousal level (low, neutral, high) for statistical analyses.

5.5.1.1 Habituation Effect

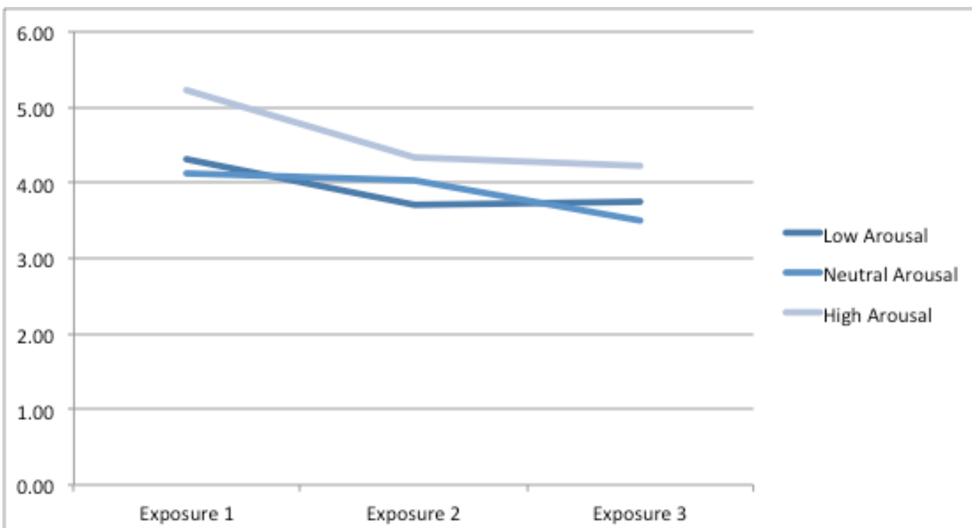


Figure 18 Habituation effect of the IAPS and IADS stimuli. Average self-reported arousal rating by arousal level.

Figure 18 shows the effect on self-reported arousal (based on SAM ratings) over time, based on exposure. For each of the arousal levels (low, neutral, high), the average reported arousal is highest in the first exposure and drops in subsequent exposures. As a result, we proceed to look at the results by trial and by arousal level based only on the condition to which participants were first exposed.

5.5.1.2 By Trial

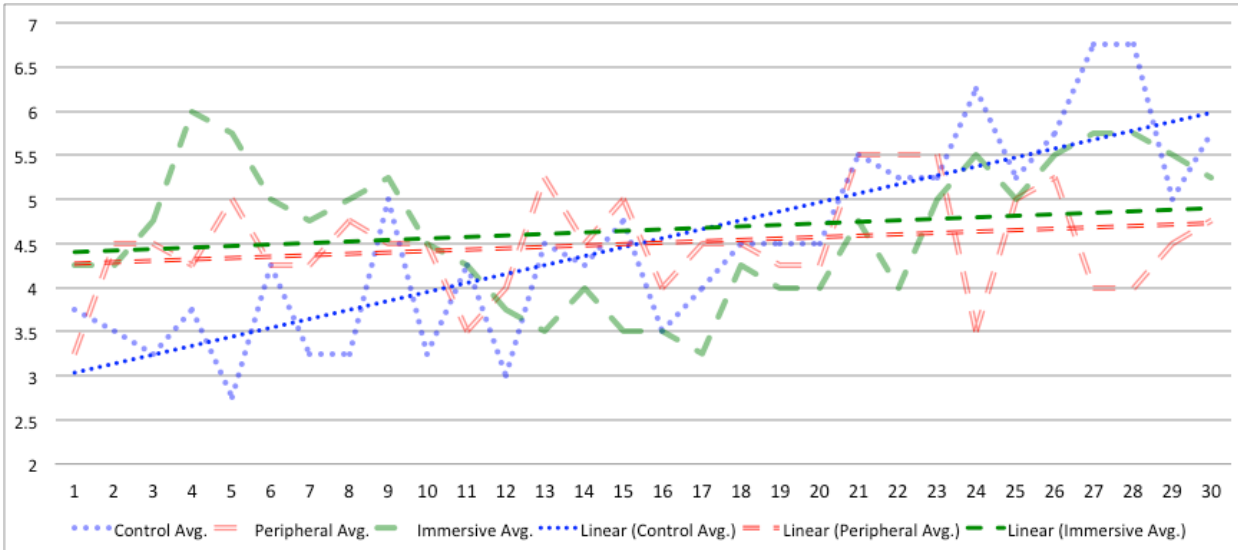


Figure 19 Average self-reported arousal by trial based on first exposed condition.

Figure 19 shows the average self-reported arousal (SAM ratings) by trial based on the condition to which participants were first exposed. In this case, each condition represents 4 participants (N=4). Additionally, trend lines show the overall trend for each condition. Here, we can see the display conditions caused a more neutral response than the control condition as we had predicted. This suggests that the IAPS and IADS arousal manipulation was successful because the control condition increases consistently as the stimulus arousal increases (recall that there was no biofeedback display in the control condition).

There is evidence that the ambient displays helped participants regulate their arousal. The trend lines show a greater difference in arousal between the control and display conditions for low-arousal stimuli than high-arousal stimuli. This suggests that participants were able to self-regulate their physiological arousal "up" but found it more difficult to regulate "down".

Because we are interested in the effect of the biofeedback display on the three levels of arousal, we aggregate the data into the three pre-determined levels of arousal, as described in section 5.4.6, for statistical analyses. The results of this data aggregation are presented in the next section.

5.5.1.3 By Arousal Level

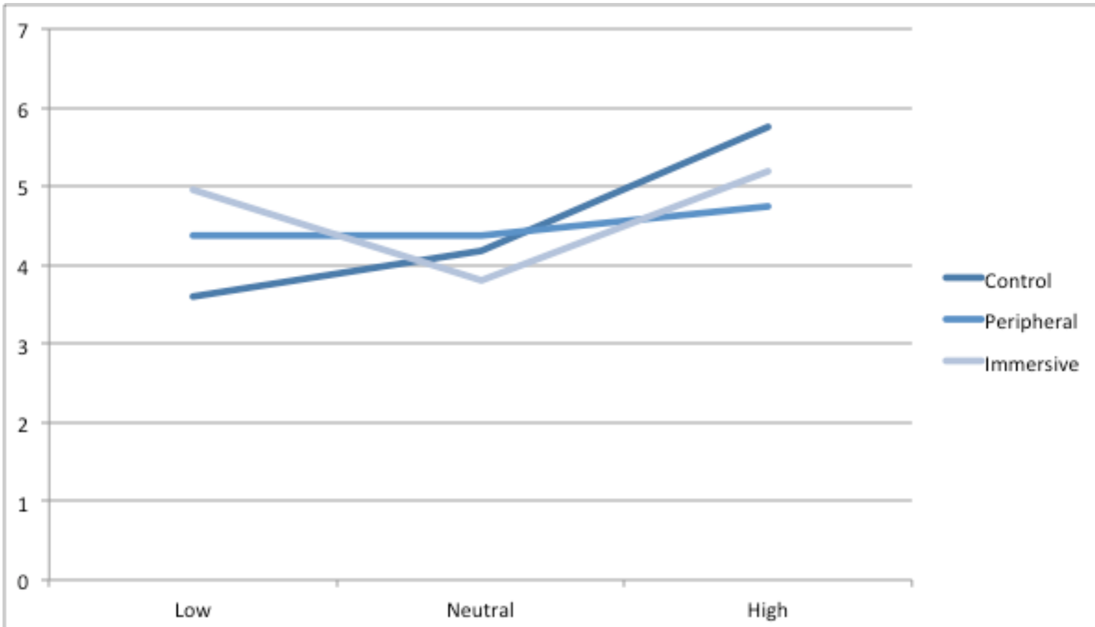


Figure 20 Average arousal between participants by first exposure.

We grouped the trials into three levels of arousal. Stimuli 1-10 belong to the low arousal level, 11-20 belong to the neutral arousal level, and 21-30 belong to the high arousal level. Figure 20 shows the average arousal over participants by the condition to which they were first exposed. This is similar to the data presented in Figure 19, but grouped by arousal level (low, neutral, high). By mitigating any habituation effect of the arousal manipulation, we can see further evidence that people were able to regulate their physiology in the display conditions. While the control condition shows a continuous increase in arousal, the peripheral condition is more flat and the immersive condition exhibits a V-shaped curve.

We now present the results of the arousal manipulation.

Effects of Arousal

Table 12 Effects of arousal manipulation for each display condition.

	Friedman, p-value	Comparison	Z	p-value
Control	X2=6.500 p=.039	Low-Neutral	-1.289	.197
		Neutral-High	-1.841	.066
		Low-High	-1.826	.068
Peripheral	X2=1.500 p=.472	Low-Neutral	-	-
		Neutral-High	-	-
		Low-High	-	-
Immersive	X2=4.500 p=.105	Low-Neutral	-	-
		Neutral-High	-	-
		Low-High	-	-

Friedman tests (df=2) showed significant differences in arousal ratings within the control condition, but not within the peripheral or immersive display conditions. This implies that participants vary their arousal ratings due to the arousal manipulation when no biofeedback display is present, but are not susceptible to the arousal manipulation when the biofeedback displays are present (see Table 12). Pairwise comparisons using Wilcoxon tests showed no significant differences between arousal levels in the control condition. Because the use of only first exposure limited the number of participants in each condition (4 in each of 3 conditions), the power of the statistical tests was limited.

5.5.1.4 Summary

In analyzing the self-report of arousal data, we have shown that:

- the IAPS/IADS arousal manipulation was successful;
- there is evidence that people were able to self-regulate their physiological arousal using the ambient displays, but people tended to do better increasing their arousal than decreasing it.

5.5.2 Iconic Memory Test

In this sub-section, we show the results of the iconic memory test. We used an iconic memory test to gauge the effects of the arousal manipulation on task performance. As with the self-report SAM data, we first demonstrate there is a learning effect of the iconic memory test. As a result, we first present the data by trial and then analyze by aggregating the data over each arousal level.

5.5.2.1 Learning Effect

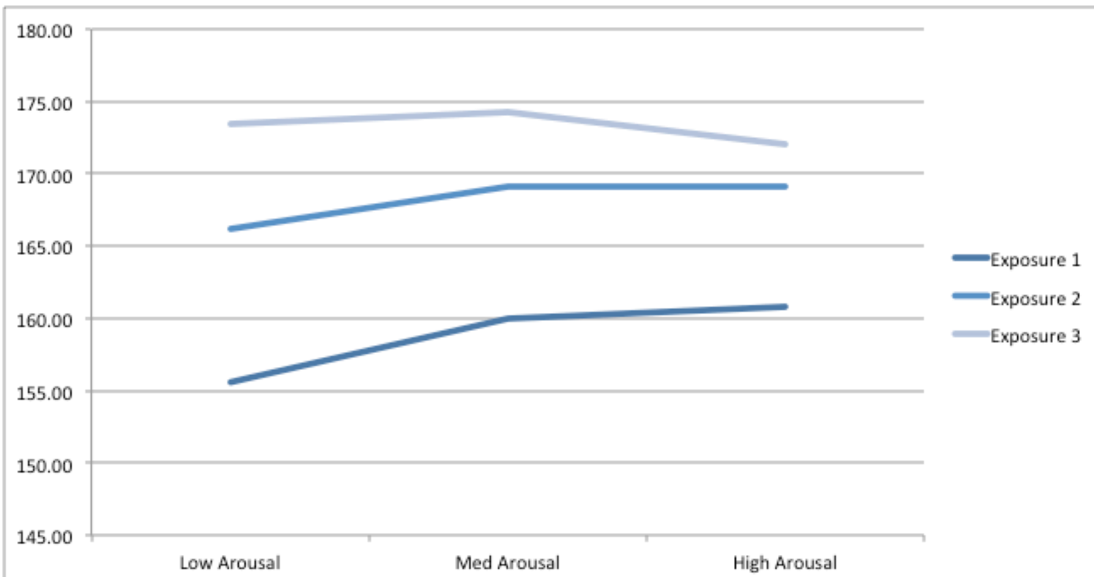


Figure 21 number of letters recalled by arousal level for each experimental exposure.

Figure 21 shows the number of letters recalled correctly by arousal level for each exposure session. Each subsequent exposure shows improved performance on the iconic memory task (an RM-ANOVA with exposure as a the within-subjects factor confirms this, $F(2,22)=17.3$, $p<.001$, all pairwise comparisons significant at $p<.05$). Based on this data, we can see there is evidence of a learning effect in the iconic memory test. Although we counter-balanced the order of presentation of conditions (so the learning effect will not differentially effect a single display condition), examining the results for the first exposure will reveal trends prior to stabilization of performance due to learning. However, as with the self-reported arousal (SAM ratings), the

IADS and IAPS arousal manipulation was most effective in the first exposure, so we analyze results for that first exposure only.

5.5.2.2 By Trial

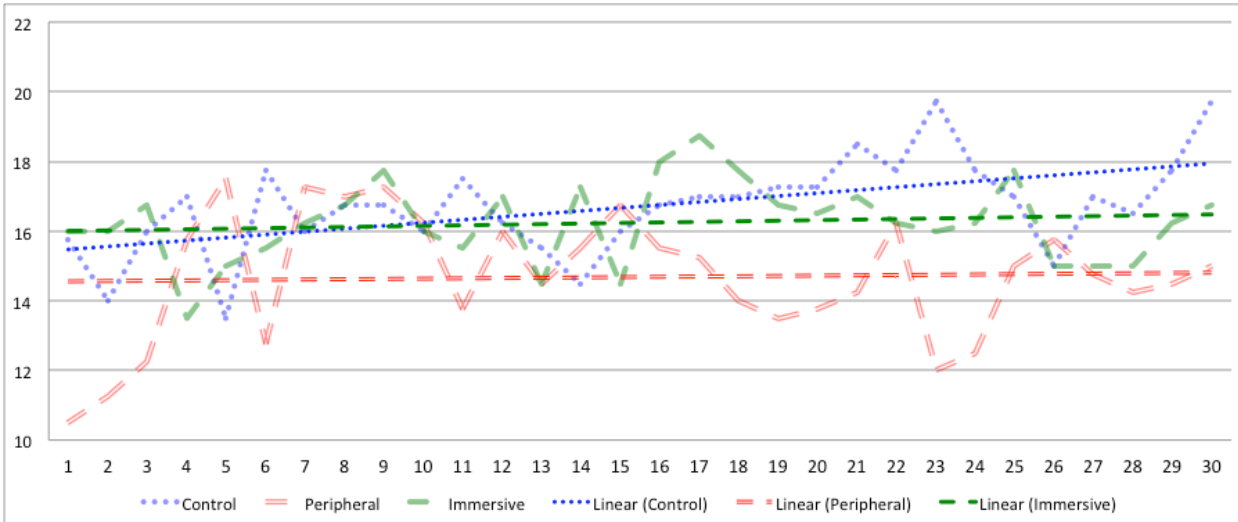


Figure 22 Average number of letters recalled correctly by trial for each condition, by first exposed condition.

Because there were five iconic memory tests per trial, we took the average of each participant's sum of the correct characters over all 5 memory tests per trial. Figure 22 shows the average number of letters recalled correctly by trial for each condition. In this case, each condition represents 4 participants (N=4). Differences between conditions seem to be greatest in the higher-arousal trials.

In the next sub-section, we aggregate the iconic memory test results by arousal level for statistical analyses.

5.5.2.3 By Arousal Level

To analyze by arousal level, we took the sum of the number of letters recalled correctly for each trial for all the stimuli within each arousal level. This process is similar to the analysis we did for the self-reported arousal data (SAM ratings). Figure 23 shows the sum of letters recalled correctly by arousal level for each of the three conditions for all participants.

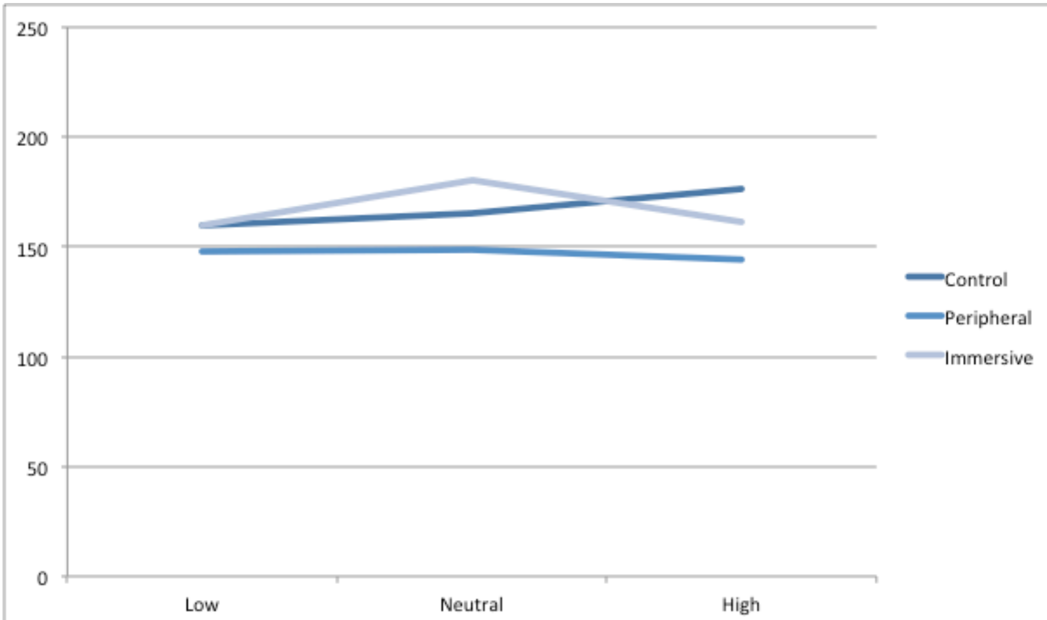


Figure 23 Sum of letters recalled correctly by arousal level for each display condition, based on condition to which participants were first exposed. N=4 per condition.

We had expected that to conform with the Yerkes-Dodson Law, participants would exhibit signs of an inverted U shape in the control condition. That is, we predicted performance to perform best in the neutral arousal level. Both group aggregate and individual results show this is not the general case (even though we had found this in the pilot). Similarly, we had expected that in the display conditions, there would be a flattening of the performance curve. We expected this because we had anticipated that as people responded to the biofeedback display to control their physiological arousal, they would perform at a more consistent level. This is because the stimuli and the biofeedback aimed to maintain a neutral arousal level in participants and our self-report data show that the biofeedback display is effective at doing this.

A repeated measures ANOVA with display condition as a between-subjects factor showed no main effect of arousal on performance, $F(18,2)=.522$, $p=.602$. Furthermore, there was no main effect of display condition on performance, $F(9,2)=.666$, $p=.537$. Finally, there were no interaction effect between display condition and arousal level, $F(4,2)=.812$, $p=.534$.

5.5.2.4 Summary

In analyzing the iconic memory test data, we have shown that:

- There is a learning effect in the iconic memory test.
- There are no significant differences due to arousal level.
- There are no significant differences due to display conditions.
- There is no significant interaction between arousal and display condition.

5.5.3 Post-Condition Questionnaires

After each session, participants answered a brief questionnaire relating to the condition they had just completed. In this sub-section, we look at the results of these questionnaires. This consisted of quantitative questions and open-ended questions about their experience. We analyze the quantitative and qualitative data separately.

5.5.3.1 Quantitative

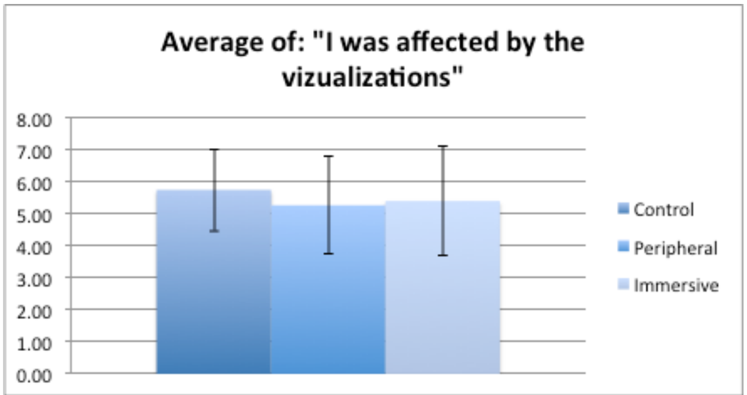
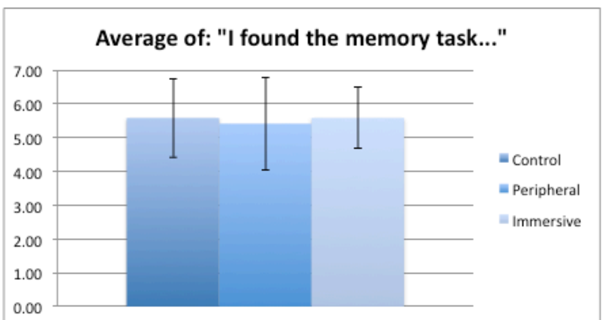


Figure 24 Average of responses to affected by the visualizations (1=disagree, 7=agree). Error bards show standard deviation.



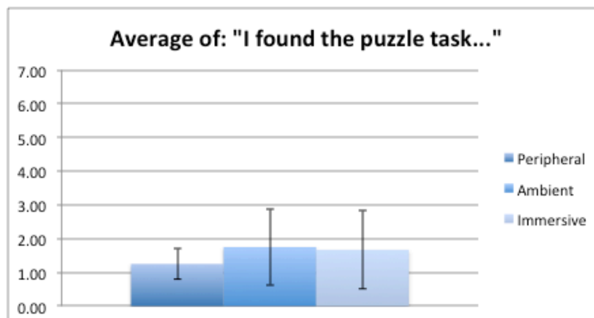


Figure 25 Average of responses to memory and puzzle task difficulty (1=easy, 7=difficult). Error bards show standard deviation.

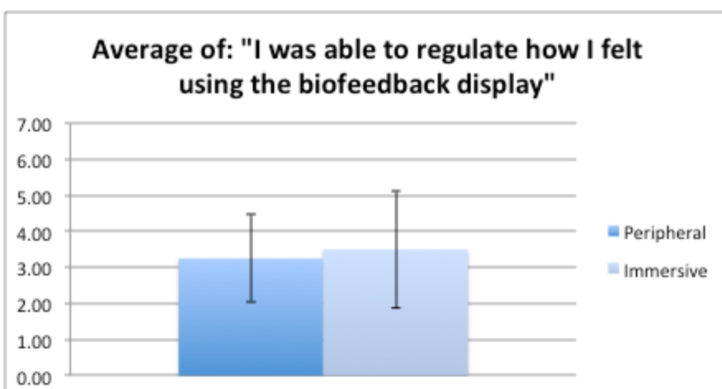


Figure 26 Average of responses to regulating physiology using display (1=disagree, 7=agree). Error bards show standard deviation.

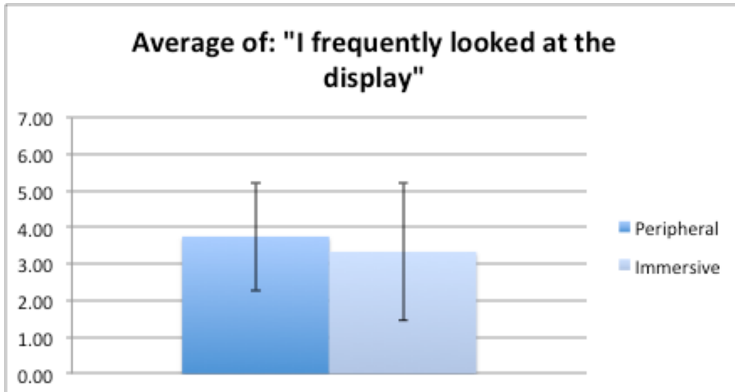


Figure 27 Average of responses to frequency looked at display (1=disagree, 7=agree). Error bards show standard deviation.

Participants were asked:

1. The sounds and images affected my physiological arousal (1=disagree, 7=agree; Figure 24)

2. I found the puzzle task (1=easy, 7=difficult; Figure 25, left)

3. I found the memory task (1=easy, 7=difficult; Figure 25, right)

4. I was able to regulate how I felt using the biofeedback display (1=disagree, 7=agree; Figure 26)

5. I frequently looked at the biofeedback display (1=disagree, 7=agree; Figure 27)

A Friedman test on questions 1-3 and a Wilcoxon test on questions 4-5 showed no differences in the participants' answers between conditions (Table 13).

Table 13 Statistical analysis of post-study questionnaire results.

Question	Test	Significance
The sounds and images affected my physiological arousal	X2=1.429	.490
I found the puzzle task…	X2=2.000	.368
I found the memory task…	X2=.231	.891
I was able to regulate how I felt using the biofeedback display	Z=-.647	.518
I frequently looked at the display	Z=-.916	.360

5.5.3.2 Qualitative/Long Answers

After each condition, participants were asked to describe their experiencing performing the jigsaw puzzle and memory task. They were asked to explain or provide any additional comments they wanted.

Several participants confirmed in their comments that the IAPS and IADS images and sounds affected how they felt. P06 stated, "the sounds affected more my mood than the images" and P07 said, "the jigsaw task was easy but the sounds and images affected [my] arousal."

One participant claimed that the images and sounds did not affect their performance on the memory task. P01 indicated, "I don't think the sounds and images had a large impact on the memory test." This was not a common theme, however, with more participants commenting about the effect the jigsaw puzzles had on the memory test. P03 reported, "disturbing pictures seem to negatively affect the memory task performance" and P04 wrote, "[the] memory task was harder when I was trying to keep calm but I was more experienced and ready for it." P07 reported, "... certain pictures and sounds affect my concentration, make me unhappy or embarrassed. That also affected the completion time in the following memory task." Finally, P10 indicated, "the jigsaw puzzles with very sad pictures – injured and dying people distracted me from memory tasks, because I was still under the impression of them."

In terms of the biofeedback display, response from participants varied. Some participants claimed that the display had no effect while others claimed that it distracted them from the primary task. P06 wrote, "it was easier to concentrate without the [peripheral] display." P10 claimed that the "biofeedback didn't affect me much." P12 wrote, "I frequently turned my head to manually inspect the biofeedback display which occasionally distracted me from the task (memory task in particular)." However, some participants claimed to have used the display to help them regulate their physiology. P09 reported, "when the disturbing images all were displayed, I used the [visualizations] of the biofeedback display to calm myself." P11 said, "I feel good when the water [is] around on the [immersive display]."

Many participants commented on the repetitive nature of the task having run it for multiple sessions with the same pictures. Some claimed this affected their performance on the jigsaw puzzles since they could remember where the pieces should be. P04 reported that the "jigsaw was too easy this time I actually could recall the images and even where to place some pieces and I could manage to regulate my feeling doing that." P05 claimed, "the jigsaw puzzles are same as the easier ones, could have solved without seeing the original one today." P06 wrote, "I found it easier this time." P08 said, "the jigsaw was super easy after 2 days of practice." Finally, P09 claimed that the "memory task was almost as difficult as first test. Puzzles were far easier to complete."

Two participants compared the effectiveness of the display conditions in the post-condition questionnaire. P09 claimed, "[it is] more difficult to control physiological response with smaller [peripheral display]." P10 reported the "bigger screen [was] more effective than smaller screen" – that is, immersive more effective than peripheral.

5.5.4 Post-Study Questionnaires

After running all three conditions, participants completed an additional post-study questionnaire on the third day. Participants were asked to compare the conditions and the displays for task performance, preference and awareness.

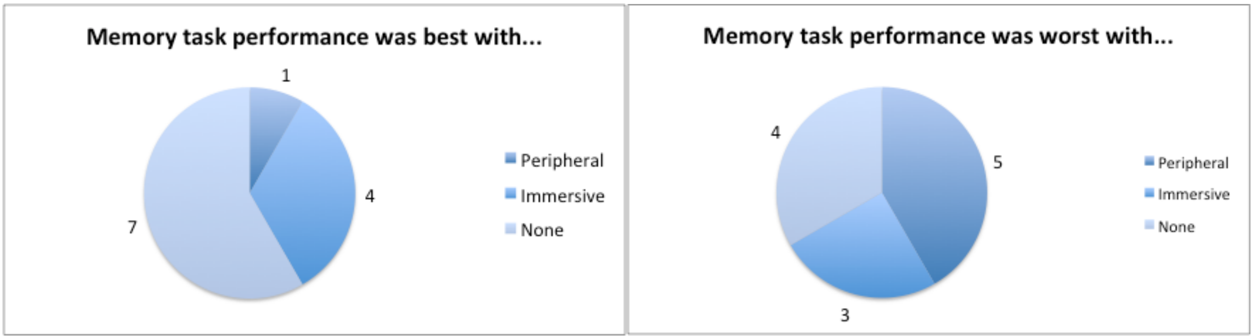


Figure 28: Distribution of responses to memory task performance questions.

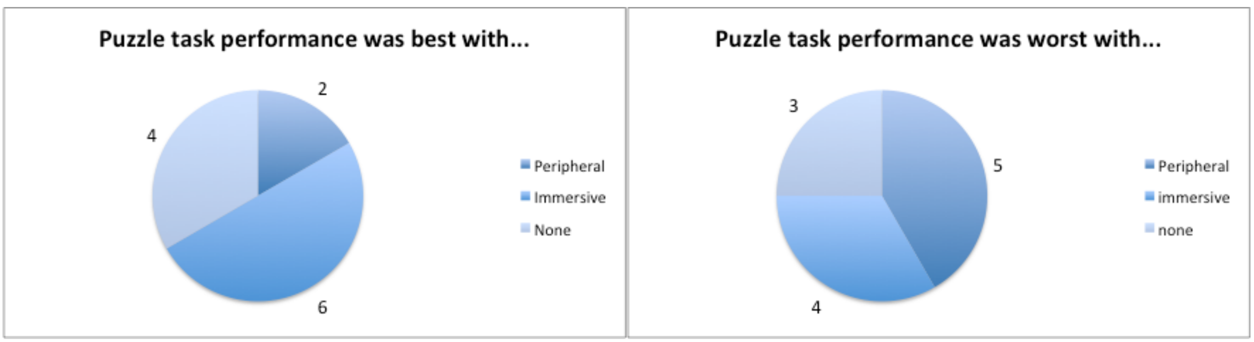


Figure 29: Distribution of responses to puzzle task performance questions.

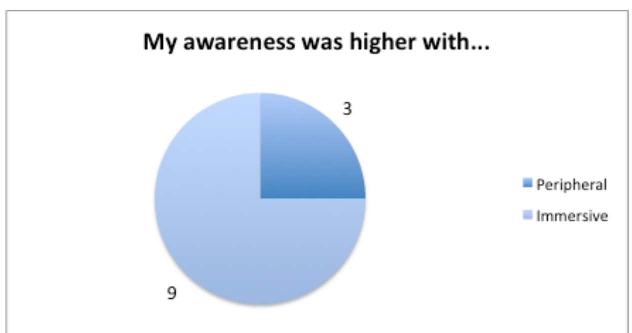


Figure 30: Distribution of responses to awareness question.

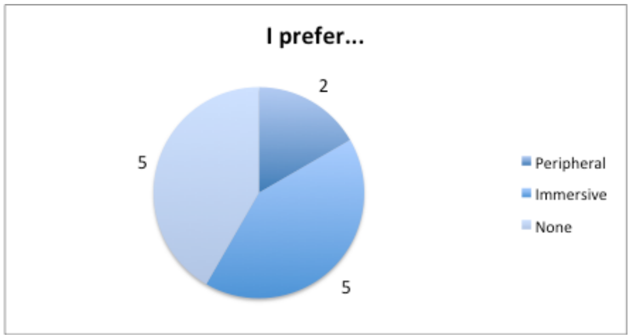


Figure 31: Distribution of responses to condition preference.

The majority of participants indicated that their performance was best on the memory test without a display (Figure 28, left), while 5 participants indicated that they performed the memory task worst with the peripheral display (Figure 28, right). Half of the participants indicated that the immersive condition provided the best performance on the puzzle task (Figure 29, left). The remaining participants were almost equally divided between no display and the peripheral display. Nearly half of the participants reported the peripheral condition being the least effective for the puzzle task (Figure 29, right). 9 of 12 participants reported the immersive condition provided the best awareness of the biofeedback visualization (Figure 30).

7 of 12 participants preferred having some display (Figure 31). Of those, 5 preferred the immersive display and 2 preferred the peripheral display. The remaining 5 participants preferred no display.

In the post-study questionnaire, we asked participants to comment on their experience with each condition. Consistent with their preference selection, participants were divided on how the type of display affected their awareness of the biofeedback visualization. Some participants liked the peripheral display because it felt more like what they were used to with a second monitor, while others preferred the immersive condition because it was easier to attend to with only their peripheral vision. P01 claimed, "I think my awareness of it was about the same on each display, but I chose peripheral display because I think I gave it more ‘undivided’ attention. I think I looked directly at the peripheral display more because it was like having a second monitor." P04 wrote, "I wasn’t comfortable with the peripheral display that I need to change the direction I look to it and back." P09 indicated, "it was easier to determine what I should be feeling without having to check back and forth between 2 screens. I could detect what I should be feeling using my peripheral vision. Also it felt as though less effort was needed with the immersive display." Finally, P10 indicated the "[immersive] display was visible even when I didn’t look at it specially. It was also in front of eyes while peripheral display was at the side."

5.6 DISCUSSION

We now present a discussion of the results obtained from this study.

5.6.1 Arousal Manipulation

Using IAPS and IADS to manipulate participants' arousal was successful. We used jigsaw puzzles consisting of IAPS images while playing IADS sounds of equivalent arousal. This is demonstrated empirically by the self-reported arousal, which shows an increase in arousal in the control condition as the stimuli increase in arousal. Furthermore, several participants commented on the effect of the IAPS and IADS images in the questionnaires.

It is important to note that some of the IAPS and IADS didn’t match with respect to content. For example, in one of the trials, a sunset IAPS image was used with an IADS sound of a cat. Stimuli were selected to match arousal as close as possible. In some cases, the much smaller IADS database limited the number of available choices. Because we were interested in arousal and not valence, we do not feel this posed a problem; however, future studies should investigate the effects of similarly-rated stimuli that differ in content.

5.6.2 Measuring Memory Performance

Despite extensive pilots using Sperling's full report of iconic memory, the test turned out to be a highly difficult task in which to measure differences as a result of an arousal manipulation. Performance is noisy, and any trends are too small to yield insights about the effects of arousal on performance. There are several confounding factors that can affect memory performance.

First, because the characters appear on screen for such a short period of time (only 50 ms), participants can be easily distracted and miss the display. In this case, participants may have received a very low score on several of the tests. This can greatly affect aggregated test scores. We observed on several occasions that participants missed the characters and recalled none of them, receiving a score of 0. We tried to train for this, but any minor interruption could interfere.

Second, because the memory test becomes quite repetitive after several sessions with 150 memory tests per session (30 puzzle trials with 5 memory tests per trial), participants may have become less interested in performing optimally as time went on. The task may have been too long to keep participants engaged. Thus, after time, participants made less effort to perform well in this task.

Third, participants used a variety of strategies to complete the full report. We observed at least one participant who attempted to memorize only the middle row and was less concerned about remembering letters on any other line. This participant was consistently satisfied with remembering 4 of the 12 characters in each test. With this level of ambition, it is difficult to gauge the effectiveness of the manipulations on the memory performance because it is not likely that 4 characters is the maximum number the participant could remember under ideal circumstances.

For future work, it is recommended to experiment with different memory tests or motivating factors (e.g., increasing participant payment with the number of correct answers) to measure the response to the arousal manipulations.

5.6.3 Learning Effects

We observed two types of learning effects in this study. First, we observed a habituation effect of the stimuli. Second, we observed a learning effect in the iconic memory test we used.

IAPS images and IADS sounds are known to cause a specific affective state in viewers. However, the authors also prohibit publishing of these images and sounds to prevent people from becoming used to their effect and reduce the affective response. Participants reacted most strongly in the first display condition to which they were exposed. After this, their response was not as strong. This does not mean that there wasn't an effect – however, it was not as strong after the first exposure. To work around this habituation effect, we looked at the data in the Results section by doing a smaller sample between-participants analysis using the condition to which they were first exposed. We do not know how habituation to the IAPS and IADS stimuli affected the iconic memory test.

The iconic memory test didn't suffer from the same type of habituation effect as the jigsaw puzzle. Each puzzle is new and randomly generated so past exposure does not increase performance. However, with practice, participants do perform demonstrably better. By looking at the average performance for all participants by level (see figure above), we can see there is an increase in performance for each exposure. The first exposure is low, while each exposure is slightly better than the last. This is also true for all three levels of arousal manipulation. We had hoped to avoid a learning effect by having participants perform an initial training task at the beginning of each session. To work around this, we performed a similar between-participants comparison by using the condition to which they were first exposed and a smaller sample size.

5.6.4 Ambient Influence

In the display conditions, we had expected that participants would be able to regulate their physiology using the displays. The visualizations of water ripples reflected the arousal state we wanted participants to target. This visualization was projected onto either the peripheral (plexiglass) display or the immersive wall display. Both of these were visible within participants' peripheral vision. This meant that they could see and attend to the visualization without conscious, dedicated effort.

The self-reported arousal (SAM ratings) shows that participants were able to regulate their physiology using the biofeedback display in both the peripheral and immersive conditions. In the low arousal level, the peripheral and immersive conditions showed arousal was higher than the control condition. This shows that people were able to increase their arousal using the biofeedback display. However, participants found it more difficult to lower their arousal in the high arousal condition. There is difference between the average reported arousal between the control and the display conditions.

This evidence supports the findings of other work (Prante et al., 2003; Jafarinaimi et al., 2005; Consolvo et al., 2008) that have demonstrated the use of peripheral technologies to positively influence behaviour. Even while engaged in specific tasks (i.e., jigsaw puzzle and memory test), participants were influenced by the ambient visualizations. Interestingly, several participants commented in the questionnaire that they did not think the displays were affecting their performance. This is also supported by existing work (e.g., Balaam et al., 2011). Furthermore, post-study questionnaires reveal that the majority of participants thought the memory task was best without the display. Unfortunately there is insufficient evidence to determine which display led to the best performance for this task.

5.6.5 Awareness Displays and Preference

It was difficult to discern specific differences in terms of performance as a result of using the different displays. However, the questionnaire data provides a few insights.

We believe that there are different types of attention committed to the peripheral and immersive displays. Because of the setup, it is easier to see the visualizations in the immersive condition than the peripheral condition. In general, the immersive display was preferred over the peripheral display. Participants rated their awareness higher and puzzle performance best with the immersive display. On the other hand, the peripheral display offered worse performance on both the memory and puzzle tasks. This suggests that the peripheral display was more distracting.

5.6.6 Yerkes-Dodson Law

Our premise for this research started with the motivation that the Yerkes-Dodson Law (YDL) predicts a range of arousal for optimal task performance. Unfortunately, because of the inconclusive results from the memory task, it is difficult to draw any conclusions to this end. Interestingly, the display conditions exhibited a U-shaped curve in self-reported arousal. However, this cannot be attributed to the YDL because the YDL reports on performance, whereas this U-shaped curve is for arousal. Our U-shaped curve is orthogonal (arousal vs. manipulation instead of performance vs. arousal) to the traditional YDL curve.

As previously noted, we know that our arousal manipulation was effective. Participants reacted in the predicted way to the IAPS and IADS stimuli. So why didn't we see the expected effect that the YDL predicts? There are a number of reasons, some of which have been previously discussed.

First, the iconic memory test may have been an insufficient measure the effect of arousal manipulation on memory performance. This same experiment could be repeated with an alternate test of memory in the future, as noted previously.

Second, while the arousal manipulation produced the desired effect, it may not have been sufficient to push participants out of the optimal range. Due to individual differences in physiological characteristics, it is possible that our participants weren't put into an arousal state that affected memory performance. It is possible that our participants, or even a large proportion of the population, require a much more severe increase in arousal in order to exhibit a negative reaction in terms of memory performance. There is some evidence to support this in our findings. Many participants demonstrated in the control condition a continued increase in performance through the increasing levels of arousal. Perhaps the peak arousal manipulation we showed was in the optimal range of arousal. Because we didn't go beyond that, we weren't able to observe the decline in performance.

5.7 CONCLUSION

In Chapters 3 and 4, we created abstract visual representations of emotion that are useful for at-a-glance understanding. In this chapter, we took the visualizations from Chapter 4 and used them on ambient displays in a biofeedback task. We used two types of ambient displays: a peripheral display made of plexiglass, and an immersive display that projects onto two walls in the corner of a room. In this experiment, participants performed a memory task while an ambient biofeedback display attempted to help them self-regulate their emotion to mitigate the effects of our arousal manipulation, using IAPS and IADS visual and aural stimuli.

As a premise to this work, we had hoped that with our ambient biofeedback displays, participants would self-regulate their arousal to flatten their performance curve, while conforming with the predicted performance curve of the Yerkes-Dodson Law. Unfortunately, data from the iconic memory test we used in this experiment was too noisy to yield significant differences between conditions. While the evidence is preliminary, our self-report data suggest that people were able to use the ambient biofeedback displays to regulate their physiological arousal. This provides further evidence that our visual representations of emotion are useful for these types of applications.

This chapter makes the following contributions. First, we are the first work to use visual representations of emotion in a biofeedback task. Second, we are the first to use an ambient biofeedback display to help people self-regulate their arousal. Finally, we have some evidence that people are able to use an ambient biofeedback display to regulate their emotion, and that a more immersive display does a better job than a peripheral display.

In the next chapter, we discuss the overall implications for our work.

CHAPTER 6

GENERAL DISCUSSION

In this chapter, we discuss the overall implications of our research. In Chapters 3 and 4, we created visual representations of emotion and evaluated them. In Chapter 5, we used the visualizations from Chapter 4 in a biofeedback task using ambient displays. We start with a synthesized discussion of visually representing emotion based on what we learned from these three chapters. We then discuss how we can design these types of visual representations for ambient influence. Next we discuss additional potential application areas for this research. And finally, we discuss limitations and future work.

6.1 VISUALLY REPRESENTING EMOTION

In this sub-section, we discuss our approaches to visually representing emotion. We start with the strategies we used and how we studied the interpretability of these visual representations. We conclude by discussing the implications for designing to represent emotion.

6.1.1 Strategies for Creating Visual Representations of Emotion

In chapter 3, we created static imagery to visually represent emotion. We did this using two strategies: compositional and algorithmic. The compositional strategy drew from art theory of composition to create representative images of emotion, and used a different approach for each quadrant of Russell's circumplex. The algorithmic strategy synthesized these into a single strategy. The results from chapter 3 led us to believe that the static imagery approach we took was insufficient for our goal of creating visualizations that are usable for at-a-glance understanding.

As a result of this work, we developed a procedural approach in chapter 4. Again, we used a different strategy for each quadrant in Russell's circumplex. But unlike the strategies used in chapter 3, this approach created animated visual representations rather than static images. Because the visualizations contained movement, this expanded the number of dimensions we could use to manipulate to represent arousal and valence. As a result, our visual representations of emotion in chapter 4 were more successfully interpreted than those in chapter 3.

Finally, we explored the use of the visual representations of emotion created in Chapter 4 in a biofeedback task using two types of ambient displays. We found that the visual representations of emotion were useful to create positive behavioural change in our participants, as they were able to self-regulate their physiological arousal to mitigate the effects of arousal-manipulating stimuli. In this experiment, we only used one visual representation of emotion on the display. We used the water ripples effect from Chapter 4 to provide feedback for the arousal axis only. Although representative of only one aspect of emotion, the effect of the visual representation was successful in helping participants self-regulate arousal.

6.1.2 Interpreting Visual Representations of Emotion

In Chapter 3 and 4, we evaluated the interpretability of our visual representations of emotion using 3 strategies. First, we asked participants to select the best emotion quadrant for each visual representation. Second, we asked participants to rate the arousal and valence values using the Self-Assessment Manikin of each visual representation. Finally, in Chapter 4 only, we asked people to identify transitions in our visual representations as they transitioned from points in arousal-valence space within an emotion quadrant.

Of these strategies, the forced-choice selection of emotion quadrant was the most successful. Particularly in Chapter 4, this demonstrated that people had little problem identifying the intended emotion quadrant to which each visual representation belonged. Ranking arousal and valence using the SAM was more challenging. Generally, people put each visualization in the correct quadrant, but the numeric values didn't always match the intended values. Using the SAM for this type of assessment is quite difficult due to individual differences in how people interpret the SAM scale. Furthermore, as previously noted, people tend not to use the extreme values of the scale.

The transitions in the visual representations used in Chapter 4 demonstrated people's ability to interpret change in the represented emotion. We performed this analysis in Chapter 4 because the visualizations were animated; this was not possible in Chapter 3 because of the nature of these visualizations. We found that transitions away from the centre of arousal-valence space (Russell's circumplex) were frequently identified correctly. As noted in Chapter 4, we believe that change blindness (Levin and Simons, 1997) is a factor that contributes to participants' inability to detect certain types of change because the transitions were noticed in one direction but not the reverse. The ability to detect and interpret change might be harder when moving from weak to strong stimuli than from strong to weak stimuli.

Finally, in Chapter 5 we used one of our visualizations from Chapter 4 to help people control their response to visual and aural stimuli. We showed that participants could interpret and use an abstract visual representation of one dimension of emotion in a secondary display to help them self-regulate their physiological arousal. Because people were successful in self-regulating their physiological response better with the display conditions than without, we believe that our visual representations of emotion are useful and applicable for biofeedback tasks. Furthermore, we believe they are suitable for use on ambient displays that are intended for understanding at-a-glance.

6.1.3 Implications for Design

Our studies have confirmed it is possible to design abstract visual representations of emotion. Because our visual representations are rooted in design principles from areas like art and dance, we have confirmed experimentally several conclusions that are relevant for researchers, designers and artists building visual representations of emotion. Visualizations with more foreground objects were rated as more arousing than those with fewer. Shapes with soft edges (e.g., circles) are rated more positive than those with hard edges (e.g., squares). Fast motion was always rated as more arousing than slow motion. Blue and white clouds were rated as more positive than red and black clouds. Neutral colours are associated with neutral valence. Water ripples, perhaps due to cultural associations, were found to be calming. Downward movement connotes sadness or depression. In combination with the colours chosen for the sad/depressed quadrant, this visualization conveyed the intended sense.

6.2 DESIGNING FOR AMBIENT INFLUENCE

In this sub-section, we discuss what we found in our attempt to use our visual representations to design for ambient influence. Ambient displays have been shown to create positive change in human behaviour. They do this by conveying information in an ambient way, relying on our ability to attend to information that is within our peripheral vision, but without us necessarily being aware that we are consuming this information. In our application of our visual representations of emotion in Chapter 5, we attempted to use our visualizations to ambiently influence participants' ability to self-regulate their physiology in a biofeedback task.

In Chapter 5, we used two types of ambient displays: a peripheral display placed beside a computer monitor, and an immersive display that projected all around the computer monitor. Evidence from our study suggested that the peripheral display was less effective than the immersive display. This is likely because the immersive display was more within participants' field of view, without the need to avert their attention to the display. We used the same visualization of emotion on both ambient displays so we could equally compare the results. However, due to limitations of our experiment, we are not able to draw conclusions about differences in the display types.

We used only one type of visualization on our ambient displays. We chose to use the water ripples effect from Chapter 4 to visualize only the arousal dimension of emotion. It was important for us to ensure the visualizations would not be deliberately distracting and would smoothly transition between states. For this reason, it was necessary to select a visual representation of a single quadrant. We used the calm visualization for these reasons, but also because we felt that the calm sentiment was related to our goal in the biofeedback task. We did however, change the background of the calm visualization to allow for representation over the full range of arousal.

We elected to use a visualization that was not likely to be perceived as distracting. There is no evidence that the visualization itself was a source of distraction, though having an additional display may have divided participants' attention. When designing visual representations of emotion for ambient influence, there are several questions related to this worth considering. Is it necessary to have a visually consistent visualization? Stated another way, can the visual representation of emotion change abruptly as the emotion it represents changes? It is possible that there are situations where we want to be aware of a significant change in the represented emotion, and in this case, visual consistency may be considered a design flaw. Finally, how much granularity in the represented emotion is important? It may be difficult for some applications or displays to represent too many gradations in arousal in valence in a visual representation of emotion. In these cases, using a high-level visual representation of emotion quadrant may be sufficient.

Our experiments have shown that our visual representations of emotion are suitable for use in an ambient application, such as our biofeedback task. However, there are special design criteria that need to be considered when visual representations of emotion are used in ambient applications. In this sub-section, we summarized some of these, though further work may be necessary for scenarios we were unable to consider.

6.3 APPLICATIONS

In this sub-section, we discuss some of the potential applications for using visual representations of emotion. In this thesis, we have already discussed the use of these visualizations for ambient displays and biofeedback tasks. We now discuss specific applications of representing and conveying emotion, how we can programmatically detect emotion, and how we can use them for multiple people.

With the success of our evaluation (in Chapter 4), we are confident that EmotiViz could be used successfully for a variety of applications. Because the abstract visual representations are naturally interpretable and useful for at-a-glance understanding, they could be used in both public and private environments. For situations, such as Subtle Stone (Balaam et al., 2010), where abstract representations are required, EmotiViz prevents the need to use pre-determined mappings between participants. EmotiViz could also be used to produce visualizations for status or mood messages in instant messaging or social media. The visualizations could accompany or entirely replace the mood message.

The current visual representations of emotion are agnostic to the source of emotion data it visualizes. By connecting to physiological sensors, we can automatically produce visualizations that reflect the underlying emotional state of the user. For people who have difficulty interpreting other people's emotions through traditional means of facial expressions and body language (e.g., people with autism spectrum disorder), visualizations could be used to help them learn to recognize the traditional cues by adding an additional channel of information.

Finally, the visualizations could be used to create an aggregate visualization to represent the emotion of a group of people. For example, we could represent the emotion of a group of people such as an audience. This could be used for visualizing their aggregate experience of a performance or an art installation. These types of applications could also be useful for interactive art exhibits.

6.4 LIMITATIONS AND FUTURE WORK

In this sub-section we discuss some of the limitations, and possible areas of future work for expanding this work. We first discuss some of the limitations due to the population used in our studies. We then discuss some of the possible privacy concerns that can arise from automated visual representation of emotion. Then we discuss some of the additional research we would like to perform to expand this area of research.

6.4.1 Limitations

Participants in our studies were from a variety of cultural backgrounds: 34 of our 63 participants in our studies in Chapter 4 were Canadian with English as their first language, whereas the remaining participants self-identified as Asian (India, China, Korea and Taiwan), Middle-Eastern (Afghanistan, Iran), African (Rwanda, South Africa) or Eastern European (Poland, Uzbekistan). Although our participants were from various cultures, over half were Canadian and there may be cultural associations that affect the interpretations of the visualizations used (e.g., fireworks, mist). Additional study is needed to determine whether our results will hold across a broader range of cultures and age groups.

We recognize that there are privacy concerns with creating these types of visual representations. Many people may not want their emotions visualized or communicated in all environments. There are valid instances where people wish to hide their emotions. We argue that although it may be possible to create these visualizations, we do not yet have a way of discretely capture people's emotional states with high accuracy without their consent. We can mitigate this issue by ensuring consent is given before this type of information is captured and communicated.

Finally, in Chapter 5 we asked people to self-regulate their arousal and then measured their response using self-report. It is important to acknowledge that participants may have responded that they were able to self-regulate their arousal to please the experimenter. However, if this were strictly the case, we would have seen lower averages in the low arousal trials. Furthermore, there likely wouldn't have been differences between display conditions.

6.4.2 Future Work

We would like to know how quickly people are able to interpret the visualizations. Our participants viewed each visualization for 15 seconds, but would they have come to the same conclusion if they had only viewed a one-second sample? Using an understanding of the visual perception of colour, geometry, and motion to create our visualizations likely makes them fast to interpret. We would also like to know how small the visualizations can be while still remaining interpretable.

We would like to perform detailed analyses on the effect of the separate visual characteristics used by EmotiViz in the animated visualizations to understand how each contributes to the conveyed emotion. With this information, we could more readily create variants of our visualizations for specific application areas where we are only interested in a single dimension of arousal and valence, or are targeting a specific audience or device and a specialized visual style is necessary.

We would also like to use sensors to measure the physiological reaction to our visualizations to see if they match self-reported measurements of arousal and valence. This information would tell us whether participants respond physiologically to our visual representations in the same way they interpret them.

We would like to further investigate how we can design visualizations so there is a stronger differentiation between points within a quadrant. This may involve investigating a different evaluation strategy other than the SAM. Additionally, we would like to determine how we could design transitions between quadrants that are less abrupt. Because we used different effects for each quadrant, it would be useful to have effects that can transition smoothly between quadrants. We would like to gain further insight into the effect of direction of transition within quadrants. It is interesting that there was an effect in one direction and not the other, and we would like to explore this result further.

Finally, we would like to further explore the use of our visual representations of emotion on ambient displays. We would like to run a similar study to that which we ran in chapter 5, using a within-subjects design to measure self-reported response to arousal manipulation using ambient displays to mitigate the effects. However, we would first do this without using the memory test to clearly establish the effect of the displays. Once this has been established, we could identify a more suitable performance test (instead of Sperling's full report of iconic memory) to show a relationship with the Yerkes-Dodson Law.

CHAPTER 7

CONCLUSION

Expressing our emotion is critical for our interpersonal relationships to succeed (Ashkanasy et al., 2000). We constantly communicate how we feel when we interact with other people. Most people are quite good at communicating how they feel face-to-face, by using emotional cues such as tonal variations in speech, body language and facial expressions (Bernieri, 1988). When we can't successfully express how we feel, we become less engaged and less interested in communicating with people (Ashkanasy et al., 2000). This negatively affects our interpersonal relationships.

Unfortunately, the emotion cues we use so well may not be available when we use interactive system or might not be suitable for all applications. In computer-mediated communication (e.g., text messaging), these cues are not available. And in interactive art projects, these cues aren't appropriate. In the real world, emotion is conveyed in a way that is natural and immediately recognized with only a glance, through facial expressions, body language and tonal variations in speech. If there are long delays by people interpreting emotion, it disrupts the flow of communication. With that in mind, any attempt to represent or convey emotion in computing environments should meet these same requirements. Whether communication is face-to-face or over a digital medium, interpreting a digital representation of emotion should be understandable with a short glance.

Existing means to convey or represent emotion in these circumstances do not work very well or are not suitable for the medium. Emoticons are limited in what they can represent. While they are suitable in text messaging, they won't work well for interactive art projects. Discrete labels of emotion suffer from the same limitations as emoticons. And recent work (e.g., Balaam, 2011) to create visual representations of emotion does not adequately address the problem because they aren't easily interpretable without prior training. Additionally, they aren't useful for at-a-glance understanding.

In this thesis, we tackled the problem that there is currently no way to convey emotion in computing environments that is usable for at-a-glance understanding and suits a variety of media. We proposed to use abstract visual representations of emotion in these situations by drawing from art and dance movement theory. We built a system for creating visual representations of emotion, and we performed four user studies to test our visualizations for interpretability and understanding. Furthermore, we integrated our visual representations into an application scenario by displaying them on ambient displays during a biofeedback task.

7.1 SUMMARY OF FINDINGS

In Chapter 3, we pilot tested a method for creating abstract visual representations of emotion using two approaches: compositional and algorithmic. Our findings in this pilot test were somewhat inconclusive and we found that our approach in this chapter was insufficient to meet our goals for the representations being naturally interpretable and suitable for at-a-glance understanding. However, we were able to use what we confirmed experimentally about compositional approaches (e.g., object shape) to inform a new approach for creating visual representations of emotion.

In Chapter 4, we took what we learned from the pilot tests in Chapter 3 to create a hybrid compositional and procedural animated visualization approach. This approach used a compositional approach for each emotion quadrant, and used a procedural strategy to control the animations within each quadrant. Furthermore, the visualizations transitioned smoothly between emotion states. We evaluated this in two parts and found that participants could interpret the represented emotion in our visualizations. We also found that participants could identify transitions in the visualized emotion state within each quadrant, especially when transitioning away from a neutral state towards an extreme state.

The visual representations of emotion we created in Chapter 4 were then used in a biofeedback application in Chapter 5. We displayed our visualizations on ambient displays (peripheral and immersive) during a biofeedback task. Participants completed a memory task while attempting to self-regulate their physiology. We found that participants were able to self-regulate their physiological arousal using the ambient displays and mitigate the effects of our arousal manipulations. However, due to limitations of our experimental design, we were not able to find an optimal range of arousal as per the Yerkes-Dodson Law for ideal task performance.

7.2 CONTRIBUTIONS

In this thesis, we made 3 main contributions.

First, we are the first to create abstract visual representations of emotion that can be used in a digital environment to convey or represent emotion without prior training so that they are useful for at-a-glance understanding. This contribution means that for applications where it is impractical to train or coordinate the meaning of visually-represented emotion, the application can use visualizations such as ours. By making our visual representations naturally interpretable, it reduces the burden on users to remember how to interpret the visualizations. And because they are understandable with only a brief glance, they are suitable for applications where they are not the focus of attention.

Second, we demonstrate that visual representations of emotion can be used on ambient displays for biofeedback tasks. Our visualizations are good candidates for use on ambient displays because they are naturally interpretable with only a brief glance.

Finally, we demonstrate that people may be able to use visual representations of emotion for biofeedback tasks to self-regulate their physiological arousal. Our participants were able to mitigate the effects of our emotion manipulation by self-regulating their arousal. The ambient display guided them to the desired level of physiological arousal to do this.

7.3 CONCLUSION

Where traditional cues of emotion do not exist or are not suitable, visual representations of emotion can be used. For example, we showed in Chapter 5 that our visualizations can be used on ambient displays to positively influence behaviour in a biofeedback task. In addition, there are many areas for which our visual representations could be useful. This includes computer-mediated communication (e.g., text messaging) and interactive art projects.

We demonstrated empirically in our user studies that our visual representations are naturally interpretable, are suitable for at-a-glance understanding, and can be used on ambient displays to positively influence human behaviour. This thesis described the design and evaluation of the visualizations in Chapters 3 and 4, and finally the design and evaluation of the visualizations in a biofeedback task in Chapter 5. With the work that we presented in this thesis, researchers and designers can create more elaborate affective computing technologies by leveraging these techniques to visually represent emotion.

REFERENCES

Albers, J. (2006). *Interaction of Color: Revised and Expanded Edition*. Yale University Press.

Arnheim, R. (1956). *Art and visual perception: a psychology of the creative eye*. University of California Press.

Ashkanasy, N.M., Härtel, C.E.J., and Zerbe, W.J. (2000). *Emotions in the workplace: research, theory, and practice*. Greenwood Publishing Group.

Association for Applied Psychophysiology and Biofeedback. (2011). Home Page. In *Association for Applied Psychophysiology and Biofeedback*. Retrieved July 13, 2012, from http://www.aapb.org/i4a/pages/index.cfm?pageid=1.

Balaam, M., Fitzpatrick, G., Good, J., and Luckin, R. (2010). Exploring affective technologies for the classroom with the subtle stone. In *Proc. CHI 2010*, 1623.

Balaam, M., Fitzpatrick, G., Good, J., and Harris, E. (2011). Enhancing interactional synchrony with an ambient display. In *Proc. CHI 2011*, 867-876.

Bernieri, F.J. Coordinated movement and rapport in teacher-student interactions. (1988). *Journal of Nonverbal Behavior 12(2)*, 120-138.

Bialoskorski, L.S.S., Westerink, J.H.D.M., and van den Broek, E.L. (2009). *New Review of Hypermedia and Multimedia, 15(2)*, 173-191.

Birnholtz, J., Reynolds, L., Luxenberg, E., Gutwin, C., and Mustafa, M. (2010). Awareness beyond the desktop: exploring attention and distraction with a projected peripheral-vision display. In *Proc. Graphics Interface 2010*, 55-62.

Boone, R.T. and Cunningham, J.G. (1998). Children's decoding of emotion in expressive body movement: The development of cue attunement. *Developmental Psychology 34*, 1007-1016.

Bradley, M.M., Greenwald, M.K., Petry, M.C., Lang, P.J. (1992). Remembering pictures: please and arousal in memory. *Journal of Experimental Psychology: Learning, Memory and Cognition, 18(2)*, 379-390.

Bradley, M.M. and Lang, P.J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry 25(1)*, 49-59.

Bradley, M.M. & Lang, P.J. (2007). *The International Affective Digitized Sounds (2nd Edition; IADS-2): Affective Ratings of Sounds and Instruction Manual*. NIMH Center for the Study of Emotion and Attention, Gainesville.

Bregman, N. J. and McAllister, H. A. (1982), Motivation and Skin Temperature Biofeedback: Yerkes-Dodson Revisited. *Psychophysiology, 19*, 282–285.

Broadhurst, P. L. (1957). Emotionality and the Yerkes-Dodson Law. *Journal of Experimental Psychology, 54*, 345-352.

Cacioppo, J. T., and Tassinary, L. G. (1990). Psychophysiology and psychological inference. In L. G. Tassinary (Ed.), Principles of psychophysiology: Physical, social, and inferential elements. Cambridge: Cambridge University Press.

Clarke, T. and Costall, A. (2008). The emotional connotations of color: A qualitative investigation. *Color Research & Application 33(5)*, 406-410.

Cole, L. W. (1911). The relation of strength of stimulus to rate of learning in the chick. *Journal of Animal Behavior, 1*, 111-124.

Colton, S., Valstar, M.F., and Pantic, M. (2008). Emotionally aware automated portrait painting. In *Proc. of DIMEA 2008*, 304.

Consolvo, S., Klasnja, P., McDonald, D.W., Avrahami, D., Froehlich, J., LeGrand, L., Libby, R., Mosher, K., and Landay, J.A. (2008). Flowers or a robot army?: encouraging awareness & activity with personal, mobile displays. In *Proc. UbiComp 2008*, 54-63.

Detenber, B.H., Simons, R.F., and Bennett, G.G. (1998). Roll 'em!: The effects of picture motion on emotional responses. *Journal of Broadcasting & Electronic Media 42(1)*, 113.

DiMicco, J.M., Pandolfo, A., and Bender, W. (2004). Influencing group participation with a shared display. In *Proc. CSCW 2004*, 614-623.

Dodson, J.D. (1915). The relation of strength of a stimulus to rapidity of habit formation in the kitten. *Journal of Animal Behavior, 5*, 333-336.

Ekman, P. (2005). Basic Emotions. In T. Dalgleish and M.J. Power, eds. *Handbook of Cognition and Emotion*, 45-60.

Esenck, M.W. (1976). Arousal, learning and memory. *Psychological Bulletin, 83(3)*, 389-404.

Gray, J.A. (2008). Brain systems that mediate both emotion and contagion. *Contagion and Emotion, 4(3)*, 269-288.

Halper, N., Mellin, M., Herrmann, C.S., Linneweber, V., and Strothotte, T. (2003). Towards an understanding of the psychology of non-photorealistic rendering. In *Proc. Workshop on Computational Visualistics 2003*, 67–78.

Hebb, D. O. (1955). Drives and the CNS. *Psychological Review, 62*, 243-254.

Hevner, K. (1935). Experimental studies of the affective value of colors and lines. *Journal of Applied Psychology 19(4)*, 385-398.

Ibáñez, J. (2011). Showing emotions through movement and symmetry. *Computers in Human Behavior 27(1)*, 561-567.

Isaacowitz, D.M., Carstensen, L.L. and Charles, S.T. (2000). Emotion and Cognition. In *The Handbook of Aging and Cognition, 2nd edition*. Ed. F.I.M. Craik and T.A. Salthouse. Mahwah, NJ: Lawrence Erlbaum Associates, 2000. 593-631.

Isen, A. M., Shalker, T. E., Clark, M., & Karp, L. (1978). Affect, accessibility of material in memory, and behavior: A cognitive loop? *Journal of Personality and Social Psychology, 36*, 1-12.

Ishihara, S. (1959). *Tests for Color-Blindness*. Kanehara Shuppan Co.

Itten, J. (1970). *The Elements of Color*. Wiley.

Jafarinaimi, N., Forlizzi, J., Hurst, A., and Zimmerman, J. (2005). Breakaway: an ambient display designed to change human behavior. In *Proc. CHI EA 2005*, 1945-1948.

Kamenica, E. (2008). Contextual Inference in Markets: On the Informational Content of Product Lines. *The American Economic Review. 98(5)*, 2127-2149.

Kaya, N. and Epps, H.H. (2004). Relationship between Color and Emotion: A Study of College Students. *College Student Journal 38(3)*, 396.

Kim, T., Chang, A., Holland, L., and Pentland, A.S. (2008). Meeting mediator: enhancing group collaborationusing sociometric feedback. In *Proc. CSCW 2008*, 457-466.

Lang, P., Bradley M. and Cuthbert, B. (2008). *International affective picture system (IAPS): Affective ratings of pictures and instruction manual*.

Lang, P.J., Greenwald, M.K., Bradley, M.M., and Hamm, A.O. (1993). Looking at pictures: Affective, facial, visceral, and behavioral reactions. *Psychophysiology 30(3)*, 261-273.

Levin, D.T. and Simons, D.J. (1997). Failure to detect changes to attended objects in motion pictures. *Psychonomic Bulletin & Review 4*, 501-506.

Maltzman, I., Kantor, W., and Langdon, B. (1966). Immediate and delayed retention, arousal, and the orienting and defense reflexes. *Psychonomic Science, 6(10)*, 445-446.

Minamikawa, A. and Yokoyama, H. (2011). Blog tells what kind of personality you have. In *Proc. CSCW 2011*, 217.

Mono, R. (1997). *Design for Product Understanding: the Aesthetics of Design from a Semiotic*

Approach. Liber.

Mould, D., Mandryk, R.L., Li, H. (2012). Emotional response and visual attention to non-photorealistic images. In *Computers & Graphics*, 6(6), 658-672.

Picard, R. W. (1997). *Affective computing*. Cambridge, MA: MIT Press.

Planalp, S. (1999). *Communicating emotion: social, moral, and cultural processes*. Cambridge University Press.

Prante, T. et al. (2003). Hello.Wall - Beyond Ambient Displays. In *Adjunct Proc. UbiComp 2003*, 277-278.

Rogers, Y., Hazlewood, W.R., Marshall, P., Dalton, N., and Hertrich, S. (2010). Ambient influence: can twinkly lights lure and abstract representations trigger behavioral change?. In *Proc. Ubicomp 2010*, 261-270.

Russell, J.A., Weiss, A., and Mendelsohn, G.A. (1989). Affect Grid: A Single-Item Scale of Pleasure and Arousal. *Journal of Personality and Social Psychology 57(3)*, 493-502.

Russell, J.A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology 39(6)*, 1161-1178.

Sharot, T. and Phelps, E.A. (2004). How arousal modulates memory: disentangling the effects of attention and retention. *Cognition, Affect and Behavioral Neuroscience, 4(3)*, 294-306.

Sherwood, J.J. (1965). A Relation between Arousal and Performance. *The American Journal of Psychology, 78(3)*, 461-465.

Shugrina, M., Betke, M., and Collomosse, J. (2006). Empathic painting: interactive stylization through observed emotional state. In *Proc. NPAR 2006*, 87–96.

Simmons, D.R. (2006). The association of colours with emotions: A systematic approach. *Journal of Vision 6(6)*, 251.

Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs: General and Applied, 75(11)*, 1-29.

Sundström, P., Stahl, A., and Höök, K. (2005). eMoto: affectively involving both body and mind. In *Proc. CHI EA 2005*, 2005–2008.

Valdez, P. and Mehrabian, A. (1994). Effects of Color on Emotions. *Journal of Experimental Psychology 123(4)*, 394-409.

Watson, D. et al. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology, 54(6)*, 1063-

1070.

Ware, C. (2004). *Information Visualization: Perception for Design, 2nd Edition*, Morgan Kaufmann.

Teigen, K. H. (1994). Yerkes-Dodson: A law for all seasons. *Theory and Psychology, 4*, 525-574.

Weiser, M. and Brown, J.S. (1996). The Coming Age of Calm Technology. In *Beyond calculation*, Peter J. Denning and Robert M. Metcalfe (Eds.). Copernicus, New York, NY, USA 75-85.

Wu, D., Courtney, C.G., Lance, B.J., Narayanan, S.S., Dawson, M.E., Oie, K.S., Parsons, T.D. (2010). Optimal Arousal Identification and Classification for Affective Computing Using Physiological Signals: Virtual Reality Stroop Task. *Affective Computing, IEEE Transactions, 1(2)*, 109-118.

Yelsma, P. and Marrow, S. (2003). An Examination of Couples' Difficulties With Emotional Expressiveness and Their Marital Satisfaction. *Journal of Family Communication 3*, 41-62.

Yerkes, R.M. and Dodson, J.D. (1908). The relation of strength of a stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Pscyhology, 18*, 459-482.

APPENDIX A: STUDY CONSENT FORMS AND QUESTIONNAIRES

UNIVERSITY OF SASKATCHEWAN

DEPARTMENT OF COMPUTER SCIENCE
UNIVERSITY OF SASKATCHEWAN
INFORMED CONSENT FORM

Research Project: **Emotion Visualization**

Investigators: Dr. Regan Mandryk, Department of Computer Science (966-4888)

Brett Taylor, Department of Computer Science (966-2327)

This consent form is only part of the process of informed consent. Please print off this form for your personal records and reference. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Please take the time to read this form carefully and to understand any accompanying information.

This study is concerned with evaluating an emotion visualization system.

The goal of the research is to determine how the create effective visualizations that represent emotion.

The session will require about 15 minutes, during which you will be asked to view images that represent emotion and rate them using standard measures of emotion from psychology.

The data collected from this study will be used in articles for publication in journals and conference proceedings.

All personal and identifying data will be kept confidential. If explicit consent has been given, textual excerpts, photographs, or video recordings may be used in the dissemination of research results in scholarly journals or at scholarly conferences. Anonymity will be preserved by using pseudonyms in any presentation of textual data in journals or at conferences. The informed consent form and all research data will be kept in a secure location under confidentiality in accordance with University policy for 5 years post publication. Do you have any questions about this aspect of the study? Please email your questions to brett.taylor@usask.ca.

You are free to withdraw from the study at any time without penalty and without losing any advertised benefits. Withdrawal from the study will not affect your academic status or your access to services at the university. If you withdraw, your data will be deleted from the study and destroyed. To withdraw from the study, send an email to brett.taylor@usask.ca indicating that you would like to withdraw from the study.

Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you have further questions concerning matters related to this research, please contact:

- Dr. Regan Mandryk, Assistant Professor, Dept. of Computer Science, (306) 966-4888, regan@cs.usask.ca

Clicking the "I agree to participate" checkbox on this form indicates you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a participant. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. If you have further questions about this study or your rights as a participant, please contact:

- Dr. Regan Mandryk, Assistant Professor, Dept. of Computer Science, (306) 966-4888, regan@cs.usask.ca
- Office of Research Services, University of Saskatchewan, (306) 966-4053

DEPARTMENT OF COMPUTER SCIENCE
UNIVERSITY OF SASKATCHEWAN
INFORMED CONSENT FORM

Research Project: **Task Performance and Arousal Feedback**

Investigators: Dr. Regan Mandryk, Department of Computer Science (966-4888)

Brett Taylor, Department of Computer Science

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Please take the time to read this form carefully and to understand any accompanying information.

This study is concerned with measuring task performance while continuously measuring physiological arousal using Galvanic Skin Response (GSR). In some conditions, you will be presented with an awareness display that visualizes the physiological arousal for optimal task performance.

The goal of the research is to determine the effect of awareness displays on physiological arousal and task performance.

This study will require 3 sessions of 40 minutes, during which you will be asked to complete jigsaw puzzles and memory tasks.

At the end of the session, you will be given more information about the purpose and goals of the study, and there will be time for you to ask questions about the research.

The data collected from this study will be used in articles for publication in journals and conference proceedings.

As one way of thanking you for your time, we will be pleased to make available to you a summary of the results of this study once they have been compiled (usually within two months). This summary will outline the research and discuss our findings and recommendations. If you would like to receive a copy of this summary, please write down your email address here.

Contact email address:____

All personal and identifying data will be kept confidential. If explicit consent has been given, textual excerpts, photographs, or videorecordings may be used in the dissemination of research results in scholarly journals or at scholarly conferences. Anonymity will be preserved by using pseudonyms in any presentation of textual data in journals or at conferences. The informed consent form and all research data will be kept in a secure location under confidentiality in accordance with University policy for 5 years post publication. Do you have any questions about this aspect of the study?

You are free to withdraw from the study at any time without penalty and without losing any advertised benefits. Withdrawal from the study will not affect your academic status or your access to services at the university. If you withdraw, your data will be deleted from the study and destroyed.

Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you have further questions concerning matters related to this research, please contact:

- Dr. Regan Mandryk, Assistant Professor, Dept. of Computer Science, (306) 966-4888, regan@cs.usask.ca

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a participant. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. If you have further questions about this study or your rights as a participant, please contact:

- Dr. Regan Mandryk, Assistant Professor, Dept. of Computer Science, (306) 966-4888, regan@cs.usask.ca
- Office of Research Services, University of Saskatchewan, (306) 966-4053

Participant's signature:____

Date:____________________

Investigator's signature:____

Date:____________________

A copy of this consent form has been given to you to keep for your records and reference. This research has the ethical approval of the Office of Research Services at the University of Saskatchewan.

POST-CONDITION QUESTIONNAIRE

Participant ID: _______ **Condition:** _______

The sounds and images affected my physiological arousal. (circle one)

Disagree	1	2	3	4	5	6	7	**Agree**

I found the *puzzle* task: (circle one)

Easy	1	2	3	4	5	6	7	**Difficult**

I found the *memory* task: (circle one)

Easy	1	2	3	4	5	6	7	**Difficult**

Please describe your experience performing the jigsaw and memory task in this condition.

____

____

____

____

____

Comments

____

____

____

____

____

over →

POST-CONDITION QUESTIONNAIRE

Participant ID: ______ **Condition:** ______

The sounds and images affected my physiological arousal. (circle one)

Disagree	1	2	3	4	5	6	7	**Agree**

I found the *puzzle* task: (circle one)

Easy	1	2	3	4	5	6	7	**Difficult**

I found the *memory* task: (circle one)

Easy	1	2	3	4	5	6	7	**Difficult**

I was able to regulate how I felt using the biofeedback display. (circle one)

Disagree	1	2	3	4	5	6	7	**Agree**

I frequently looked at the biofeedback display. (circle one)

Disagree	1	2	3	4	5	6	7	**Agree**

Please describe your experience performing the jigsaw and memory task in this condition.

____

____

____

____

____

Comments

____

____

____

____

____

over →

POST-STUDY QUESTIONNAIRE

Participant ID: ______

I think my performance on the *memory* task was best with:

No Display	Ambient Display	Ubiquitous Display

I think my performance on the *memory* task was worst with:

No Display	Ambient Display	Ubiquitous Display

I think my performance on the *puzzle* task was best with:

No Display	Ambient Display	Ubiquitous Display

I think my performance on the *puzzle* task was worst with:

No Display	Ambient Display	Ubiquitous Display

Which display did you prefer?

No Display	Ambient Display	Ubiquitous Display

My awareness of the biofeedback was higher with:

Ambient Display	Ubiquitous Display

Please explain your choice for the previous question:

____

____

____

____

Comments

____

____

____

____

____

APPENDIX B: PILOT STUDIES DATA TABLES

SAM Results

Q	Loc.	Strategy	Arousal			Valence		
			Exp.	Mean	SD	Exp.	Mean	SD
1	1	C1	9	6.20	1.71	1	4.76	1.94
2	2	C1	9	2.92	1.58	5	4.40	1.71
3	3	C1	9	4.16	1.89	9	4.76	1.51
4	4	C1	7	5.48	1.92	3	4.84	1.57
5	5	C1	7	4.28	1.70	7	4.80	1.41
6	6	C1	5	2.88	1.72	1	3.88	1.42
7	7	C1	5	3.60	2.00	5	5.16	1.60
8	8	C1	5	3.44	1.85	9	5.68	1.41
9	9	C1	3	3.64	1.63	3	4.36	1.70
10	10	C1	3	3.08	1.68	7	5.12	1.48
11	11	C1	1	2.72	1.28	1	4.20	1.68
12	12	C1	1	3.08	1.68	5	4.52	1.29
13	13	C1	1	3.16	1.62	9	4.96	1.77
14	1	C2	9	6.96	1.86	1	5.44	1.53
15	2	C2	9	3.12	1.42	5	5.12	1.48
16	3	C2	9	4.60	1.94	9	4.64	1.19
17	4	C2	7	5.56	2.00	3	4.64	1.55
18	5	C2	7	4.80	2.12	7	4.60	1.66
19	6	C2	5	4.32	2.04	1	4.64	1.87
20	7	C2	5	3.32	1.63	5	5.04	1.62
21	8	C2	5	4.08	1.82	9	5.84	1.55
22	9	C2	3	4.76	2.05	3	5.16	1.57
23	10	C2	3	3.68	2.01	7	5.32	1.52
24	11	C2	1	2.84	1.49	1	4.00	1.26
25	12	C2	1	3.04	1.37	5	4.52	1.39
26	13	C2	1	3.52	1.50	9	5.08	1.22
27	1	Alg.	9	5.64	1.78	1	5.40	1.73
28	2	Alg.	9	5.64	1.87	5	5.52	1.69
29	3	Alg.	9	5.52	1.98	9	4.96	1.57
30	4	Alg.	7	4.68	1.86	3	4.60	1.32
31	5	Alg.	7	5.28	1.81	7	5.16	1.43
32	6	Alg.	5	4.44	1.47	1	4.44	1.08

Q	Loc.	Strategy	Arousal			Valence		
			Exp.	Mean	SD	Exp.	Mean	SD
33	7	Alg.	5	4.48	1.50	5	4.84	1.28
34	8	Alg.	5	4.52	1.73	9	5.16	1.43
35	9	Alg.	3	3.76	1.76	3	3.84	1.11
36	10	Alg.	3	4.08	1.55	7	4.44	1.23
37	11	Alg.	1	3.24	1.59	1	3.60	1.29
38	12	Alg.	1	3.56	1.64	5	4.36	1.25
39	13	Alg.	1	3.36	1.66	9	5.04	1.21

Categorical Results

Q	Loc.	Exp. Cat	Frequencies				X2	Sig.
			angry	excited	bored	calm		
1	1	angry, enraged	5	**15**	1	0	14.857	**0.001**
2	2	neutral	0	0	8	13	1.190	0.275
3	3	excited, joyful	3	6	5	7	1.667	0.644
4	4	angry, enraged	9	10	1	1	13.857	**0.003**
5	5	excited, joyful	1	6	6	8	5.095	0.165
6	6	neutral	0	0	14	7	2.333	0.127
7	7	neutral	1	0	8	12	8.857	**0.012**
8	8	neutral	0	1	6	14	12.286	**0.002**
9	9	bored, sad	3	0	12	6	6.000	0.050
10	10	calm, satisfied	0	3	4	**14**	10.571	**0.005**
11	11	bored, sad	2	0	**14**	5	11.143	**0.004**
12	12	neutral	0	0	12	9	0.429	0.513
13	13	calm, satisfied	1	1	4	**15**	25.286	**0.000**
14	1	angry, enraged	**14**	5	1	1	21.476	**0.000**
15	2	neutral	0	1	11	9	8.000	**0.018**
16	3	excited, joyful	0	9	7	5	1.143	0.565
17	4	angry, enraged	**13**	6	1	1	18.429	**0.000**
18	5	excited, joyful	2	9	6	4	5.095	0.165
19	6	neutral	1	6	9	5	6.238	0.101
20	7	neutral	0	0	10	11	0.048	0.827
21	8	neutral	0	1	4	16	18.000	**0.000**
22	9	bored, sad	11	3	1	6	10.810	**0.013**
23	10	calm, satisfied	0	2	6	**13**	8.857	**0.012**
24	11	bored, sad	2	0	**15**	4	14.000	**0.001**

Q	Loc.	Exp. Cat	Frequencies				X2	Sig.
			angry	excited	bored	calm		
25	12	neutral	1	1	13	6	18.429	**0.000**
26	13	calm, satisfied	0	0	4	**17**	8.048	**0.005**
27	1	angry, enraged	5	14	1	1	21.476	**0.000**
28	2	neutral	4	10	5	2	6.619	0.085
29	3	excited, joyful	0	10	3	8	3.714	0.156
30	4	angry, enraged	4	4	9	4	3.571	0.312
31	5	excited, joyful	2	**12**	3	4	11.952	**0.008**
32	6	neutral	4	4	10	3	5.857	0.119
33	7	neutral	0	7	5	9	1.143	0.565
34	8	neutral	0	5	3	13	8.000	**0.018**
35	9	bored, sad	1	3	**14**	3	19.952	**0.000**
36	10	calm, satisfied	1	4	7	9	7.000	0.072
37	11	bored, sad	0	1	**19**	1	30.857	**0.000**
38	12	neutral	1	1	8	11	14.619	**0.002**
39	13	calm, satisfied	0	0	4	**17**	8.048	**0.005**

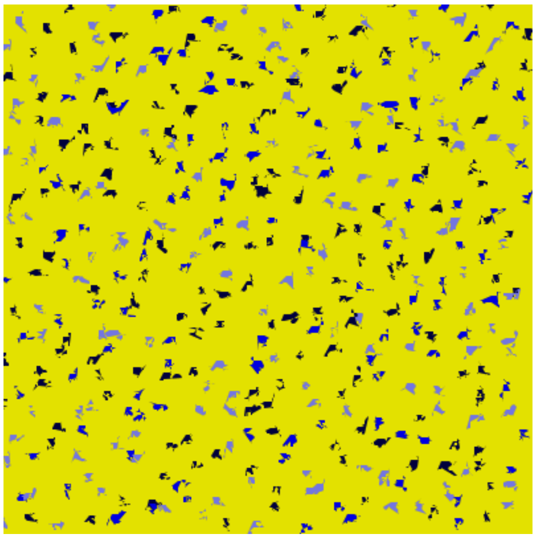
APPENDIX C: IAPS AND IADS STIMULI SELECTED

Trial	IAPS Description	IAPS Number	Arousal	Valence	IADS Number	IADS Description
1	lamp	7175	1.72	4.87	satori-1*	Meditative music
2	fork	7080	2.32	5.27	satori-2*	Meditative music
3	window	7490	2.42	5.52	satori-3*	Meditative music
4	book	7090	2.61	5.19	kazue-1*	Meditative music
5	emptypool	9360	2.63	4.03	262	yawn
6	flowers	5000	2.67	7.08	809	harp
7	filecabinets	7224	2.81	4.45	812	choir
8	cow	1670	3.05	6.81	708	clock
9	rabbit	1610	3.08	7.82	810	beethoven
10	ocean	7545	3.28	6.84	809	harp
11	father	2339	4.16	6.72	810	beethoven
12	boat	5395	4.23	5.34	150	seagull
13	fire	9635.2	4.62	4.38	246	heartbeat
14	scared child	9041	4.64	2.98	382	shovel
15	spider	1230	4.85	4.09	170	night
16	sunset	5830	4.92	8	102	cat
17	runners	8220	5.19	6.5	243	couplesneeze
18	injuredchild	3301	5.21	1.8	816	guitar
19	roaches	1274	5.39	3.17	242	female cough
20	snake	1030	5.46	4.3	320	office1
21	man on fire	9635.1	6.54	1.9	261	baby cry
22	rafters	8400	6.61	7.09	353	baseball
23	attack	3530	6.82	1.8	288	creep
24	mutilation	3130	6.97	1.58	713	sirens
25	rockclimber	8160	6.97	5.07	367	casino2
26	bungee	8179	6.99	6.48	815	rocknrol
27	soldier	9410	7.07	1.51	275	scream
28	mutilation	3080	7.22	1.48	424	carwreck
29	skydivers	8185	7.27	7.57	282	fight2
30	skier	8030	7.35	7.33	360	rollercoaster

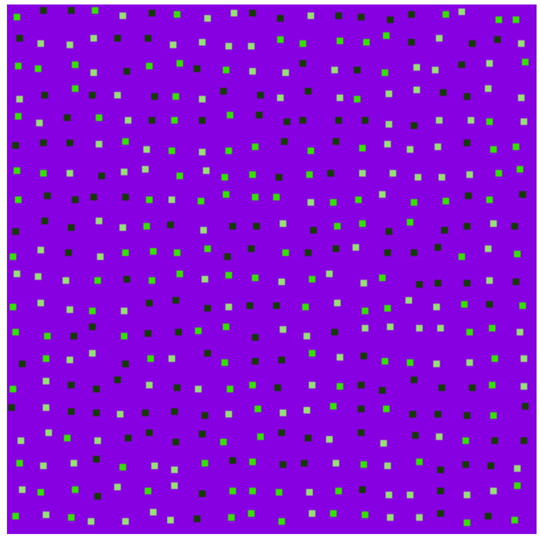
Note*: The IADS sound database did not contain sounds with sufficiently low arousal to match the IAPS stimuli. In these cases, a quiet meditative new-age music clip was selected.

APPENDIX D: VISUAL REPRESENTATIONS OF EMOTION GENERATED BY EMOTIVIZ

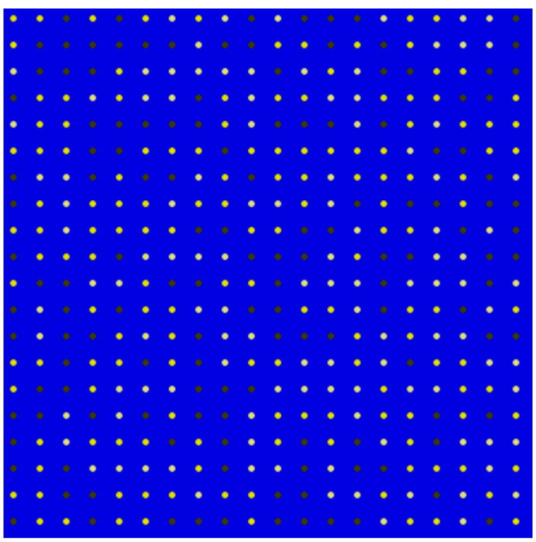
Visualizations from Chapter 3 – Algorithmic Strategy



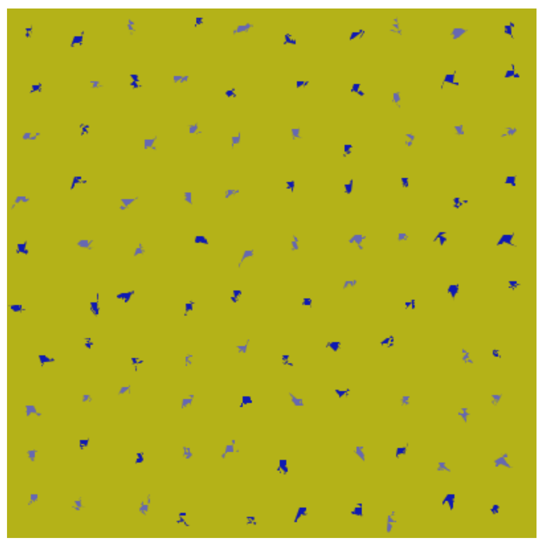
High Arousal, Negative Valence



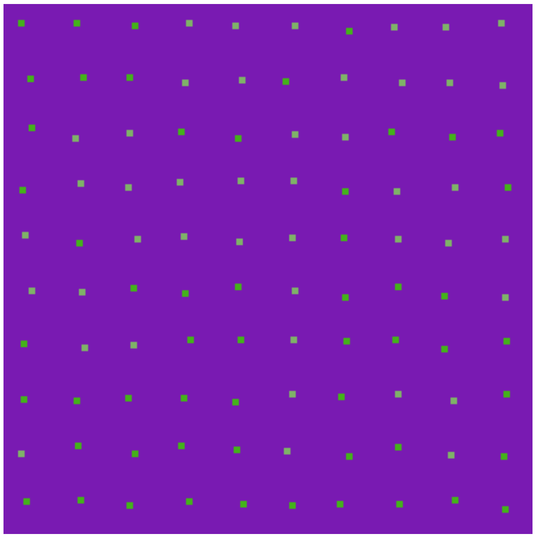
High Arousal, Neutral Valence



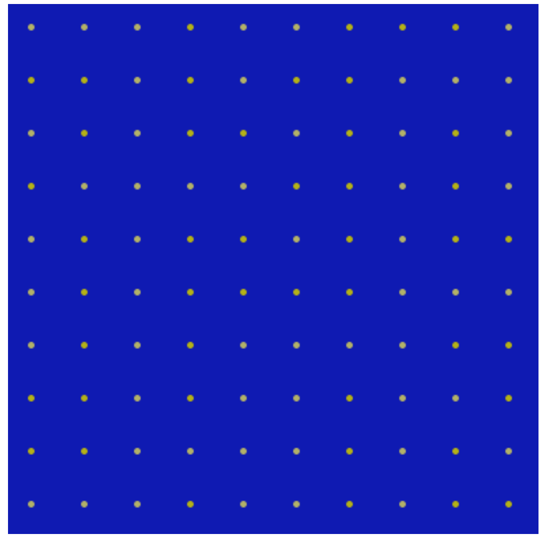
High Arousal, Positive Valence



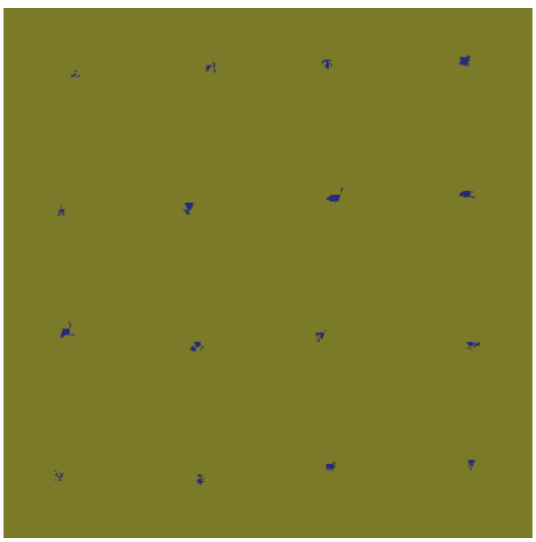
Neutral Arousal, Negative Valence



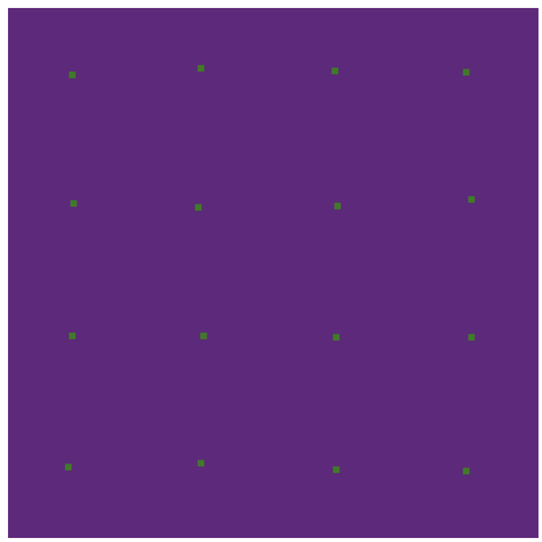
Neutral Arousal, Neutral Valence



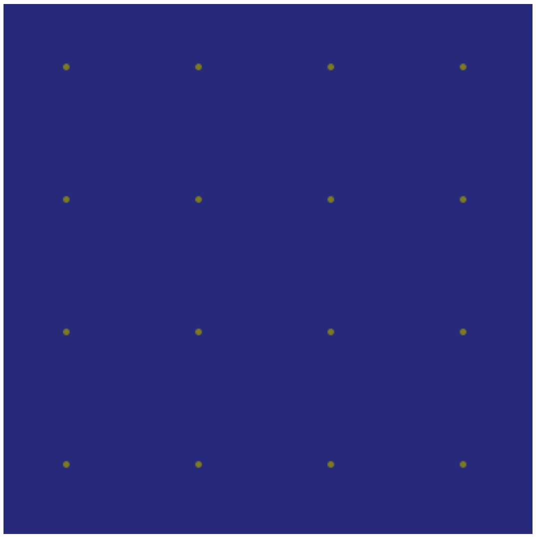
Neutral Arousal, Positive Valence



Low Arousal, Negative Valence



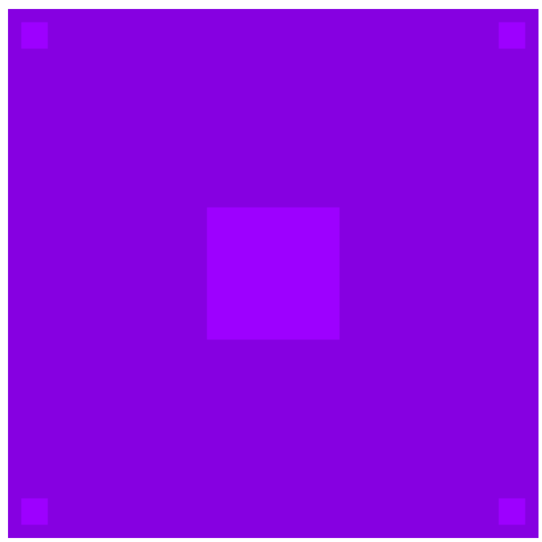
Low Arousal, Neutral Valence



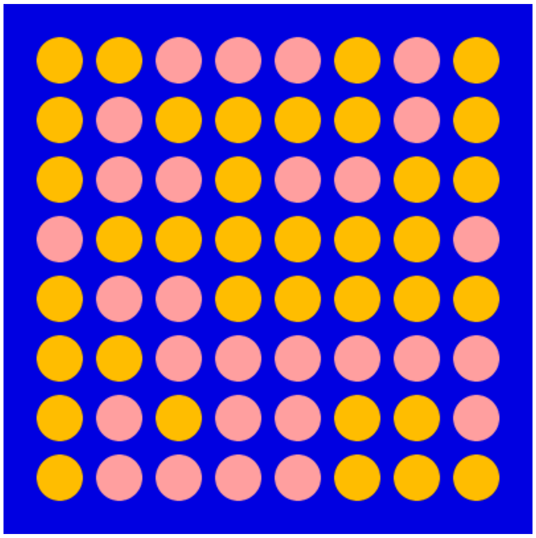
Low Arousal, Positive Valence

Visualizations from Chapter 3 – Compositional Strategy #1

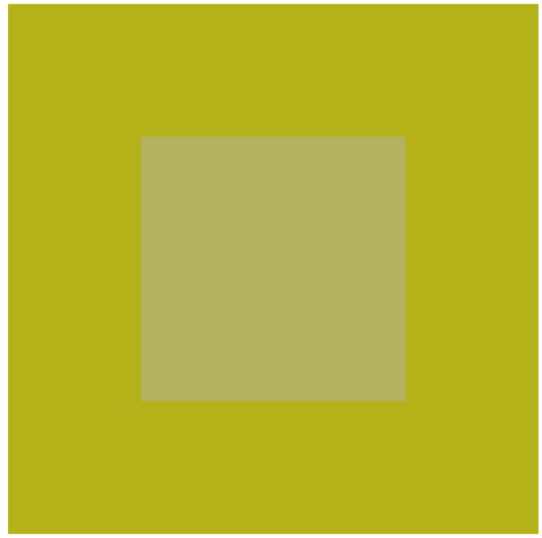
High Arousal, Negative Valence



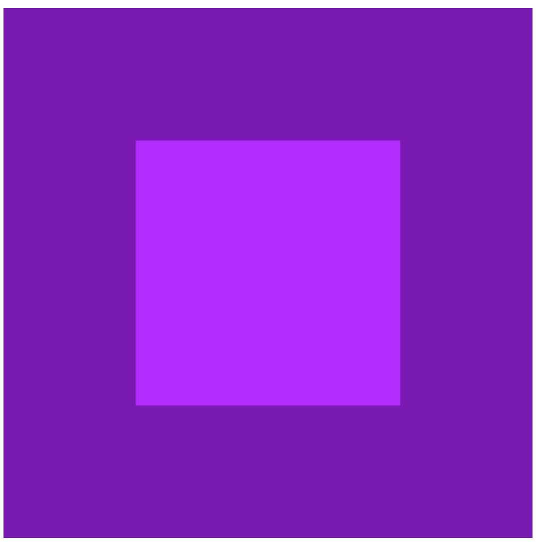
High Arousal, Neutral Valence



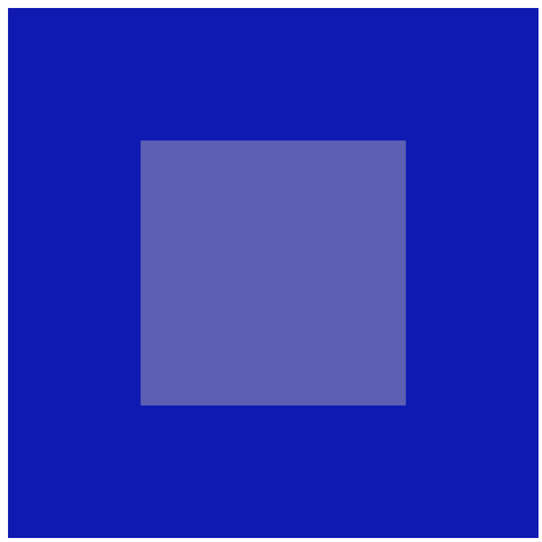
High Arousal, Positive Valence



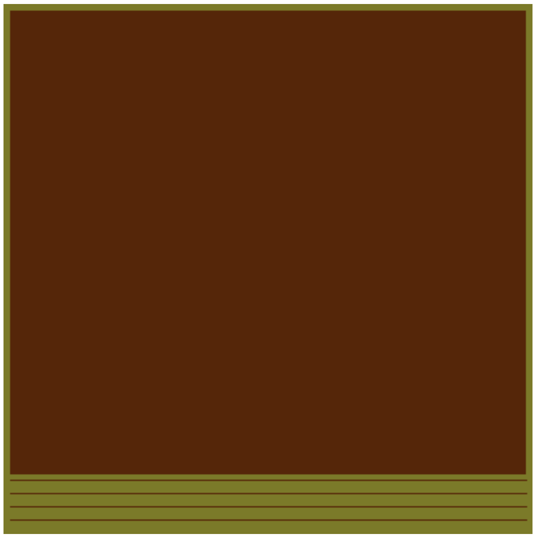
Neutral Arousal, Negative Valence



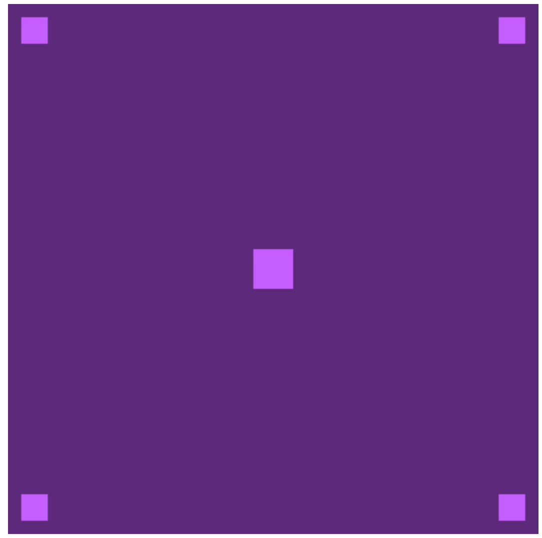
Neutral Arousal, Neutral Valence



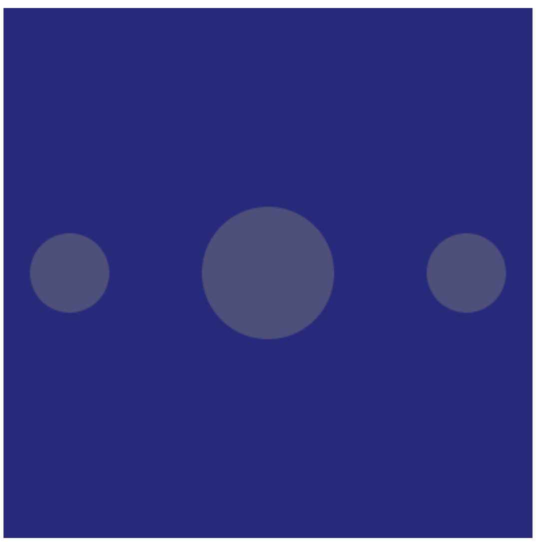
Neutral Arousal, Positive Valence



Low Arousal, Negative Valence

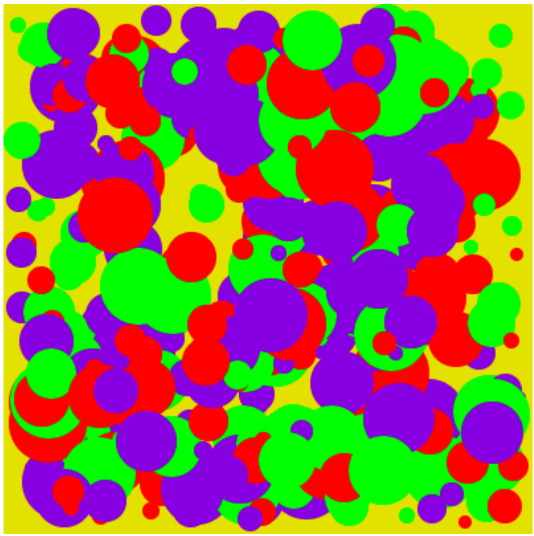


Low Arousal, Neutral Valence

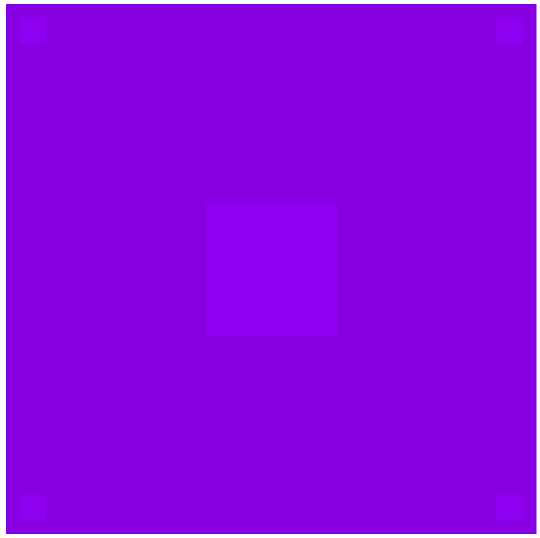


Low Arousal, Positive Valence

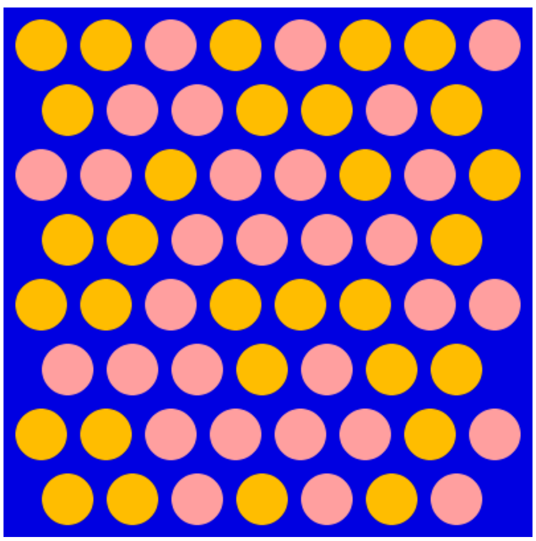
Visualizations from Chapter 3 – Compositional Strategy #2



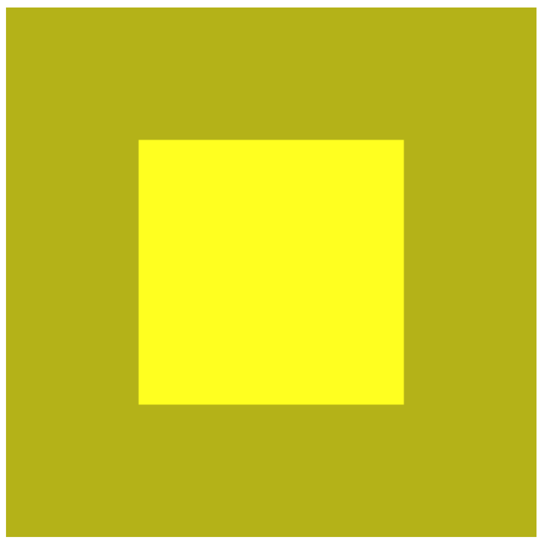
High Arousal, Negative Valence



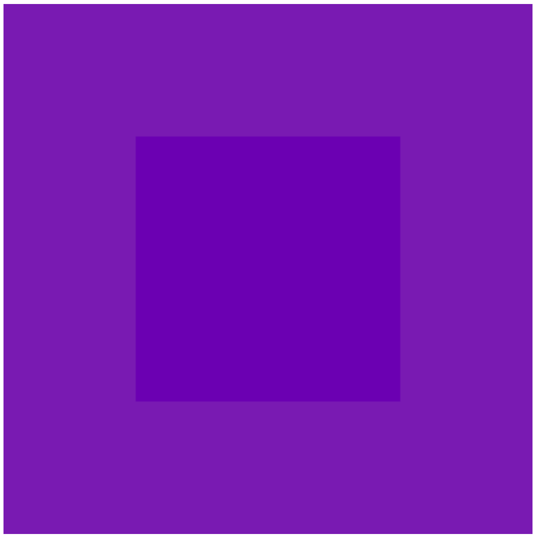
High Arousal, Neutral Valence



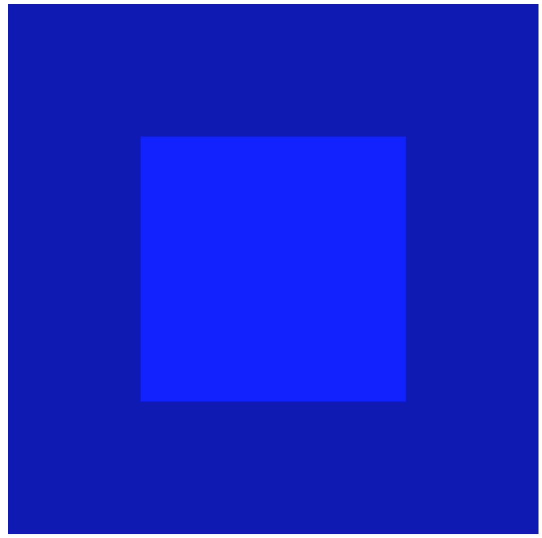
High Arousal, Positive Valence



Neutral Arousal, Negative Valence

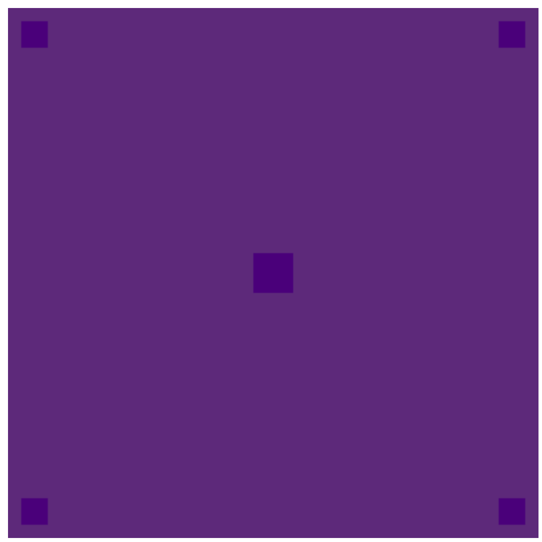


Neutral Arousal, Neutral Valence

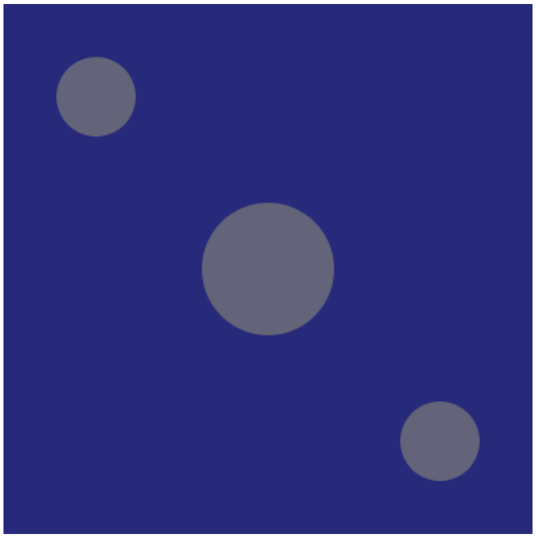


Neutral Arousal, High Valence

Low Arousal, Negative Valence



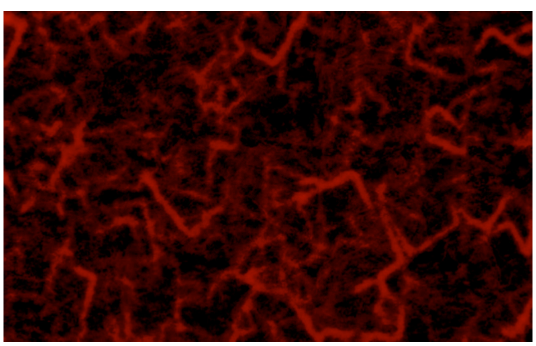
Low Arousal, Neutral Valence



Low Arousal, Positive Valence

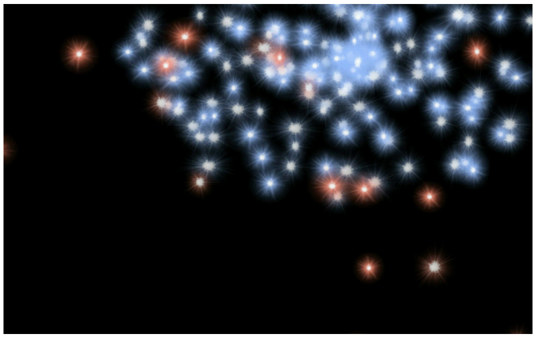
Visualizations from Chapter 4

Note that these visualizations are animated, and these static images do not represent the movement aspect of the way in which emotion was conveyed.

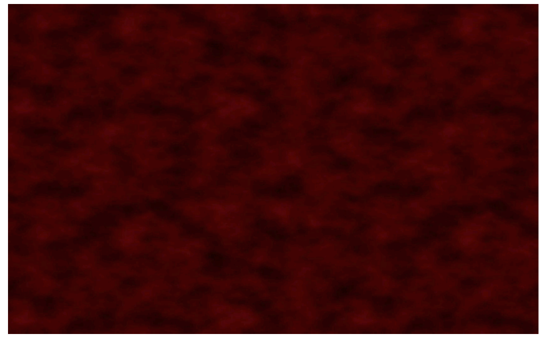


High Arousal, Negative Valence

High Arousal, Neutral Valence

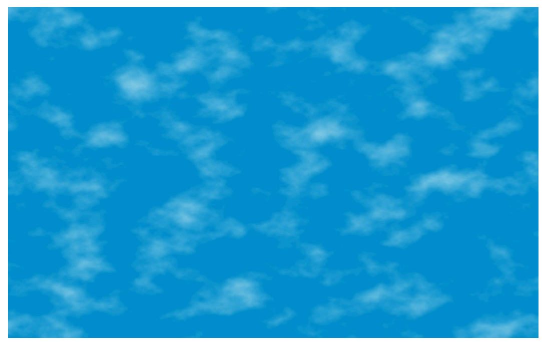


High Arousal, Positive Valence

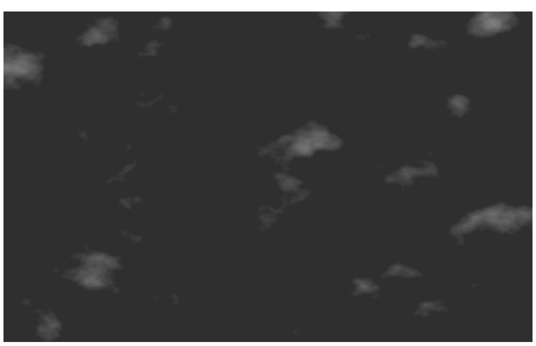


Neutral Arousal, Negative Valence

Neutral Arousal, Neutral Valence



Neutral Arousal, Positive Valence



Low Arousal, Negative Valence

Low Arousal, Neutral Valence

Low Arousal, Positive Valence